

Full Length Research Paper

An update of sweet potato viral disease incidence and spread in Ethiopia

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Received 20 April, 2020; Accepted 14 July, 2020

Sweet potato (*Ipomoea batatas* (L.) Lam.) is an important root crop for poor farmers in developing countries. Since the late 1980s, viral diseases have increasingly become a threat to sweet potato production in Ethiopia. This review paper presents the role of sweet potato production for ensuring food security, the level of sweet potato virus research, including the types of viral species identified and their current level of incidences in Ethiopia. *Sweet potato feathery mottle virus* (SPFMV), *Sweet potato chlorotic stunt virus* (SPCSV), *Sweet potato virus 2* (SPV2), *Sweet potato virus G* (SPVG), and *Cucumber mosaic virus* (CMV) were reported in Ethiopia, where the first two are the most common and exist at high incidences. In addition, this paper discusses the virus vectors, virus transmission methods to new farms, factors exacerbating the rate of viral incidence and the methods used to reduce the incidences. Moreover, it highlights methods of sweet potato viruses' detection and cleaning of infected materials in use and the challenges encountered towards the efficient utilization of the methods. Finally, we suggest major intervention techniques that will integrate all key players in managing the impact of the virus on sweet potato production to improve productivity and ensuring food security in Ethiopia. The findings obtained from this review could be an input for the current research on sweet potato improvement (both planting materials and routines) in Ethiopia.

Key words: Sweet potato, research, virus, detection, planting, infection, production.

INTRODUCTION

Sweet potato (*Ipomoea batatas* (L.) Lam.) is an important root crop in developing countries. It is grown in 115 countries, where China is the leading producer. Amongst the main crops produced in the world, sweet potato is ranked seventh on the base of production volume (FAO,

2017). In most developing countries, it ranks fifth in the order of food importance (Som, 2007) and is the third main crop after cassava and maize in East Africa (FAO, 2014).

There are many reasons why sweet potato is important

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and preferred by growers. It is a food, feed and an important raw material for the industry (Bovell-Benjamin, 2007). Growers choose to grow sweet potato crops because of its ability to tolerate a wide range of growth conditions, it has lower demand for agricultural inputs, high yielding potential per unit area per unit time, ease of cultivation and an effective vegetative propagation method (Woolfe, 1992). Moreover, it has a high nutritive value (primarily of carbohydrates and vitamins) and is suitable to grow on marginal lands. Due to all these merits, sweet potato remains a competitive crop for food security in developing countries (Gibson, 2009).

Sweet potato improvement researches have been started in the early 1980's in Ethiopia, and so far, 26 improved varieties were released with their appropriate production packages (Shonga et al., 2013). On the other hand, little is known and less attention was given to sweet potato viruses and the associated diseases until very recently. Furthermore, there is no adequately documented information on viral diseases (virus species, incidence, impacts on yield and efforts made so far to reduce its incidence) in Ethiopia. Thus, this research gap has been a problem for researchers in identifying, prioritizing and tackling constraints to sweet potato production, as well as in designing appropriate disease management strategies for Ethiopia. Therefore, the objectives of this paper are 1) to review the literature on sweet potato viral species identified and the level of incidence and impact of the diseases on sweet potato production in Ethiopia 2) to identify research questions and bring to the attention of researchers and stakeholders 3) suggest possible alleviation strategies.

Production status of sweet potato and its role in food security in Ethiopia

Sweet potato production and its role to combat food insecurity is currently increasing in Ethiopia. Based on the production volume, Ethiopia is ranked the seventh sweet potato producer in the world (FAO, 2017). Sweet potato stands second, after potato (*Solanum tuberosum*) in area coverage among the root crops grown in the country, but is ranked first in terms of production per hectare (Central Statistical Agency, 2015). Sweet potato is cultivated on 130,000 ha of land in Ethiopia, with an annual total production of 2, 0089, 290 tons (FAO, 2017). Over 95% of the sweet potato cultivations are in the densely populated areas in the southern, southwestern and eastern parts of the country (Central Statistical Agency, 2010). Oromia Regional State and Southern Nations Nationalities and Peoples Region (SNNPRS) are the two major producers contributing 52.15 and 47.15% respectively to the annual sweet potato production (Central Statistical Agency, 2010).

The contribution of sweet potato to poor farmers of

Ethiopia has so far been underestimated. Farmers of Ethiopia cultivated sweet potato for several years either as a main or as a supplementary source of food. Farmers produce sweet potato mainly for own consumption and also to some extent as sources of income. Sweet potato is a food security crop for at least 20 million Ethiopians (Tofu et al., 2007). It is highly valued when there is shortage of other crops (Emanna, 1990). This is because it withstands drought and performs well on less fertile soil without significant compromises of yield. Sweet potato crop has potential to improve food and nutritional security (especially the orange fleshed with pro vitamin A precursor) for poor farmers (Tsou and Hong, 1992). It is amongst the underutilized crops in most Sub-Saharan Africa countries, including Ethiopia, compared to other sweet potato producing countries in Asia. Recently, there are efforts by various NGOs and Government institutions to introduce sweet potato to other regions in the northern, eastern and western parts of the country, to diversify their crop production (Shiferaw et al., 2014; Aldow, 2017). However, sweet potato yields can vary drastically due to viral diseases (Alemu, 2004; Tesfaye et al., 2013).

Sweet potato-infecting viruses identified in Ethiopia

There is no clear evidence of when or how sweet potato viruses were introduced into Ethiopia. However, *Sweet potato feathery mottle virus* (SPFMV) was first identified around three decades ago, at a place called Nazret [(Scientific Phytopathological Laboratory, 1986)]. There has been no sweet potato virus study in Ethiopia before the study by Alemu (2004). Since then, a number of surveys have been conducted to document the incidences, severities and identities of sweet potato viruses; mostly performed in southern Ethiopia (Alemu, 2004; Adane, 2010; Tesfaye et al., 2011, 2013). The infecting viruses were tested in samples obtained from sweet potato germplasm collections maintained at the research sites and in farmers' fields, mostly located in southern Ethiopia. The presence of five sweet potato infecting viruses in Ethiopia was confirmed by these survey studies (Table 1), out of the thirty virus species known to infect sweet potato worldwide (Clark et al., 2012). Moreover, the surveys also revealed that SPFMV is the most frequently detected virus in southern Ethiopia, followed by SPCSV. None of the other viruses tested [*Sweet potato mild mottle virus* (SPMMV), *Sweet potato latent virus* (SPLV), *Sweet potato chlorotic fleck virus* (SPCFV), *Sweet potato caulimo-like virus* (SPCaLV), *Sweet potato mild speckling virus* (SPMSV) and *C-6 virus*] were detected in these surveys. However, a recent report indicated that all these six viruses have later been detected in germplasm, imported into Ethiopia for the purpose of screening for diseases incidence and other traits (Shiferaw et al., 2017). A recent work has reported

Table 1. List of areas surveyed, number of sweet potato samples tested and sweet potato specific viruses detected in Ethiopia.

Location of sampling	Total no. of samples tested	Numbers of samples reacted positive to virus and mixed infection*								References
		SPFMV	SPCSV	SPFMV+SPCSV (SPVD)	SPFMV +SPVG	SPFMV+SPC SV +SPVG	CMV	SPVG	SPV2	
Southern Ethiopia	318	196	0	0	0	0	-	3	-	(Alemu 2004)
Hawassa ARC	57	22	21	7	0	0	-	0	1	(Adane 2010)
Wondo Genet ARC	127	79	13		0	0	0	0	2	
Hawassa Research Center	6	6	6	0	0	0	0	0	0	Dugassa and Feyissa (2011)
SNNPRP and eastern Oromia	970	146	125	90	0	0	0	44	0	
Symptomatic samples	235	134	115	88	25	0	0	28	0	Tesfaye et al. (2011)
Asymptomatic samples	735	13	10	0	7	0	0	15	0	
Hawassa ARC	32	+	+	+	0	+	+	+	0	Wondimu et al. (2012)
Southern Ethiopia Farmer field	166	ni	ni	83	ni	0	ni	ni	ni	
Research stations		ni	ni	+ (46- 100%)	ni	0	ni	ni	ni	Tesfaye et al. (2013).

*Presence of the viruses were confirmed by test methods listed in table 2. SPVD: Sweet potato virus diseases, SPFMV: *Sweet potato feathery mottle virus*, SPCSV: *Sweet potato chlorotic stunt virus*, SPVG: *Sweet potato virus G*, CMV: *Cucumber Mosaic Virus*, SPV2: Sweet potato virus 2, +: detected but number not indicated, -: not tested for, ni: no information if tested or not, and ARC: Agricultural Research Centre.

the detection of sweetpotato badinaviruses, *sweet potato mastreviruses*, *sweet potato virus C* and some viroids in high yielding sweet potato varieties from Ethiopia (Dereje, unpublished).

SPFMV and SPCSV, their mixed infections: A threat to sweet potato production in Ethiopia

Sweet potato viral diseases are the second most important limiting factor to sweet potato production next to the weevil in Ethiopia (Fite et al., 2014). SPFMV and SPCSV are the most frequently detected viruses in Ethiopia. For example, high infection of these viruses reported in sweet potato germplasm collections in the research fields at the Hawassa and Wendo Genet

Agricultural Research Centers (Adane, 2010). The extent of SPFMV and SPCSV incidence and its economic importance has been described previously in many more sweet potato producing locations in the SNNPRS (Alemu, 2004; Tesfaye et al., 2011, 2013). SPFMV and SPCSV can occur as single infections or as mixed infections. Single infection of these viruses results in mild symptoms (and many times as symptomless infections). However, when both viruses occur as mixed infection, the symptoms are more severe and results in what is known as Sweet potato viral disease (SPVD). Single and multiple infections of sweet potato plants with SPFMV, SPCSV and SPVG and sweet potato virus II (SPV2) are also not uncommon in Ethiopia (Adane, 2010; Dugassa and Feyissa, 2011; Tesfaye et al.,

2011). Recent studies also confirmed that SPFMV and SPCSV infections and their co-infection have become serious problems in the farmers' and sweet potato multipliers' fields (Dereje, unpublished) (Mebrate, 2018).

Summary of virus survey literature review reveals few studies that covered only limited locations were conducted on sweet potato virus diseases in Ethiopia (Figure 1). Moreover, most of the studies were limited to locations mostly in SNNPRS (Adane, 2010; Tesfaye et al., 2011; 2013). Unfortunately, no study has been carried out in other sweet potato growing areas of Ethiopia, except a single study data that was generated from samples collected from Hararge zone, eastern Ethiopia (Tefaye et al., 2011). Therefore, extensive surveys that cover all the

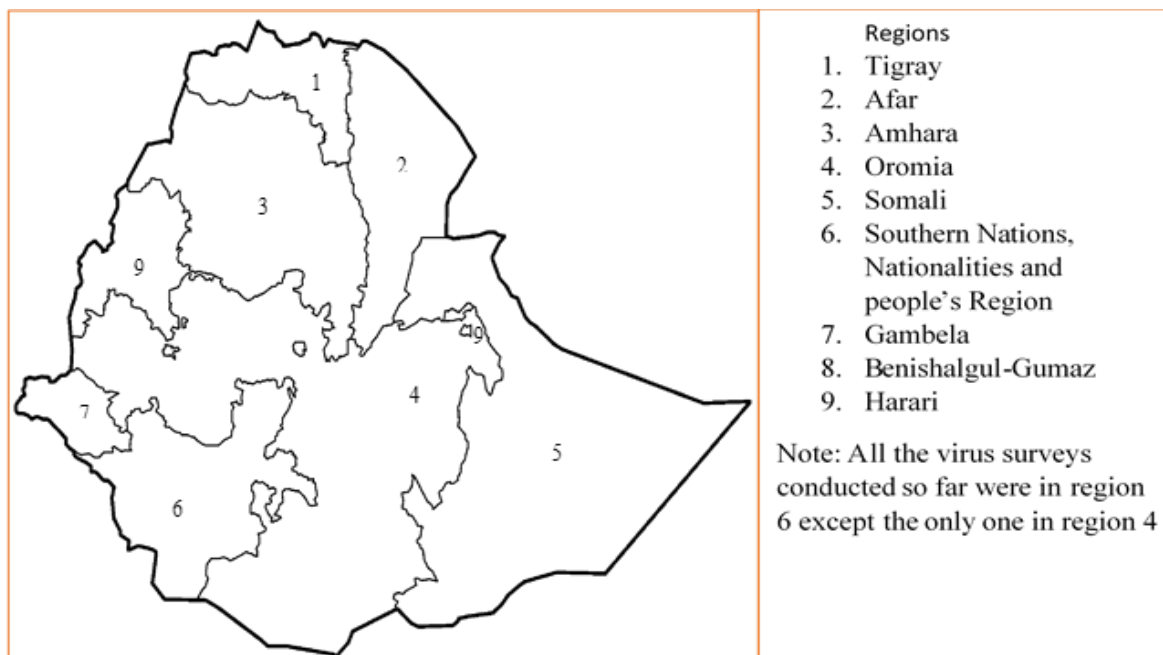


Figure 1. The nine regions in Ethiopia.

sweet potato production regions are required to determine the current status of sweet potato viral diseases in each location to determine the appropriate preventive measures. Furthermore, it is also important to study virus incidences in wild relatives of sweet potato, since these can act as alternative hosts to viruses infecting cultivated sweet potato.

Disease incidence and yield reduction

The incidences of viruses in sweet potato research sites and in farmer's fields in the southern part of Ethiopia are summarized in Table 1. Sadly, research sites (germplasm collections and experimental stations) are more infected than the farmers' fields. Up to 80 and 100% virus incidences were reported in the samples collected from farmers' fields and germplasm collection sites, respectively (Adane, 2010). The author reported one or more viruses detected in those samples. Likewise, Tesfaye et al. (2013) reported incidences of 75% in the samples from farmer's fields and 100% in the experimental stations. The relatively higher incidences of SPCSV and SPFMV documented in samples collected from germplasm collections at research stations might be an indicator of the fact that the germplasms imported for adaptation trials were sources of virus infection. Exchange of germplasm between countries for adaptation trials has been a common practice in Ethiopia. However, farmers still grow few improved and mostly

local cultivars. Free exchange of planting materials could also be one of the largest contributors to the spread and distribution of viruses in Ethiopia. Therefore, designing and establishing strong quarantine procedures is required to prevent introduction of infected materials. Moreover, any imported germplasm should be restricted from field planting for propagation and adaptation trials until confirmed free of pathogen and insect pest. The above findings confirmed the status of viral diseases incidence in germplasm in Ethiopia is similar to that of Uganda, which ranges from 86 to 100% (Aritua et al., 2007). However, it differs from that of Kenya 48% (Ateka et al., 2004) and Tanzania 17 to 33% (Ndunguru and Kapinga, 2007). Thus, the incidences and severity of sweet potato viral diseases in East Africa are variable.

SPVD is the main bottleneck of sweet potato production in many parts of the world as reviewed by (Gibson and Kreuze, 2015). As stated before, SPFMV and SPCSV incidences are at a high level and SPVD is widely spread in SNNPR, Ethiopia, (Adane, 2010; Tesfaye et al., 2011). SNNPR is the main source of germplasm for trials and planting materials for production to all production regions in the country. Hence, virus-infected materials distributed from SNNPR could be an important sweet potato production threat of the country. A general decline in sweet potato productivity per hectare was observed over the decades (FAO, 2017). However, no reliable studies have been conducted to estimate the extent of yield loss by virus infections.

As mentioned previously in this report, the incidence of

viral diseases in Ethiopia is similar to that of Uganda. If the incidence of viral diseases correlates with the observed yield loss in Uganda, one could expect losses of up to 98% in Ethiopia (Gibson et al., 1998; Karyeija et al., 1998; Mukasa et al., 2003). A recent study that compared infected and healthy plants in screen house in Ethiopia showed up to 100% losses of yield, which depending on varieties and infecting virus(es) infection (Dereje, unpublished). However, yield losses are also dependent on the varieties grown, viral type present and climatic condition during the growth period. For example, the incidence of sweet potato viruses in China can be up to 90% (Wang et al., 2010), although the average yield loss due to viral diseases ranges between 20-30% (Feng et al., 2000). Nevertheless, the high incidences of viral diseases in Ethiopia, the lack of efficient diagnostic tools, and lack of virus-free planting materials are among the factors that continue to contribute to the dissemination of viruses within the country. Thus, there is a need to set up diagnostic laboratories and reliable detection methods.

Methods of virus detection

Virus testing employs different diagnostic methods. For virus detection, methods that range from the screening of disease symptoms in the fields to the use of more sophisticated molecular detection techniques can be applied (Boonham et al., 2014; Jeong et al., 2014). The available technological level, existing laboratory facilities and competent workforce to conduct the work influences the choice of any of the method. Assays based on the biological and serological properties of viruses is the commonly used method in developing countries. However, molecular detection methods are more rapidly emerging this days.

Many sweet potato infecting-viruses induces no or mild symptoms on infected plants. For example, SPFMV infected plants is mostly symptomless. Sweet potato Badnavirus causes no symptoms (Kreuze et al., 2017). In this circumstance, ELISA could not be a good testing method in regards due less virus titer in symptomless host. Therefore, grafting sweet potato to an indicator plant is very useful, especially when the virus titer concentration in the original host is below the detection limit of serological tests; Enzyme Linked Immunosorbent Assay (ELISA). However, grafting alone cannot decided the type of the infecting virus and needs other reliable method that target specific species. Unfortunately, grafting is a lengthy method (at least a month) and needs greenhouse space. In some cases, some viruses induce no symptoms even in the highly susceptible indicator plant *Ipomoea setosa* (Clark et al., 2012). Therefore, identification of viruses solely based on symptom expression on host plants is not recommended and

should be combined with other testing methods.

ELISA is widely used in many laboratories across the globe. This method is very quick and sensitive for detecting plant viruses mostly that induces high virus titer in infected host, provided that antibodies are available. As described before, due to the low virus titer, an initial grafting to *Ipomoea setosa* or other hosts is required to increase virus titer to detectable levels in many cases. It also requires laboratory equipment, which makes ELISA less accessible, particularly in laboratories in developing countries. In recent years, a combination of serological and nucleic acid-based assays is common plant virus detection methods. Lack of proper laboratory facilities and technical capabilities, access to reagents have limited many developing countries from establishing these detection methods. The methods used to detect viruses in sweet potato plants grown in Ethiopia are summarized in Table 2.

Sources of virus infectious agents and possible means of dissemination

As previously stated, there is no clear evidence of when or how sweet potato viruses were introduced into Ethiopia. Nevertheless, it is believed that viruses were introduced after the 1980s, when the exchange of planting material for breeding purposes increased between many African countries. Many sweet potato cultivars were introduced to Ethiopia between 2001 and 2003 from African (Tofu et al., 2007). Consequently, viruses problem in southern Ethiopia was recognized during 2006 to 2009 (Shiferaw et al., 2014). For example, as presented in this paper, recently six new viruses not previously identified in farmer's fields in Ethiopia were detected in sweet potato germplasm that was introduced from international sources (Shiferaw et al., 2017). This suggests that the exchange of materials within and between places can be one of the main sources for infecting new areas.

Even though breeding programs have been running since the late 1980s and sweet potato is the second most widely grown root crop in Ethiopia, there are no well-developed sweet potato certified seed production systems. Consequently, there is no established mechanism to generate and supply healthy planting materials to the farmers. Farmers obtain planting materials from many different sources none of them go through reliable phytosanitary control. Most farmers save their own sweet potato planting material from the previous year harvest, while others obtain it either through local exchange from neighboring farmers or buy it from nearby local markets (Dereje, unpublished). Such exchange of planting materials is done irrespective of the knowledge if the material is virus-free. For example, picture in Figure 2A is an example of farmer's fields infected with virus and

Table 2. Virus detection methods used in Ethiopia.

Methods used for detection	References
Based on biological properties of the virus Biological (graft-inoculation)*	Alemu (2004)
Nucleic acid based (PCR, Sequencing of coat protein)*	Alemu (2004)
Based on viral proteins NCM-ELISA, DAS and TAS-ELISA	Alemu (2004); Adane (2010); Dugassa and Feyissa (2011); Tesfaye et al. (2011); Wondimu et al. (2012); Tesfaye et al. (2013)

*Performed in Germany on Ethiopian plant material. NCM-ELISA: Nitrocellulose membrane-Enzyme linked immunosorbent assay, DAS-ELISA: double antibody sandwich enzyme-linked immunosorbent assay, TAS-ELISA: Triple antibody sandwich enzyme-linked immunosorbent assay, PCR: polymerase chain reaction

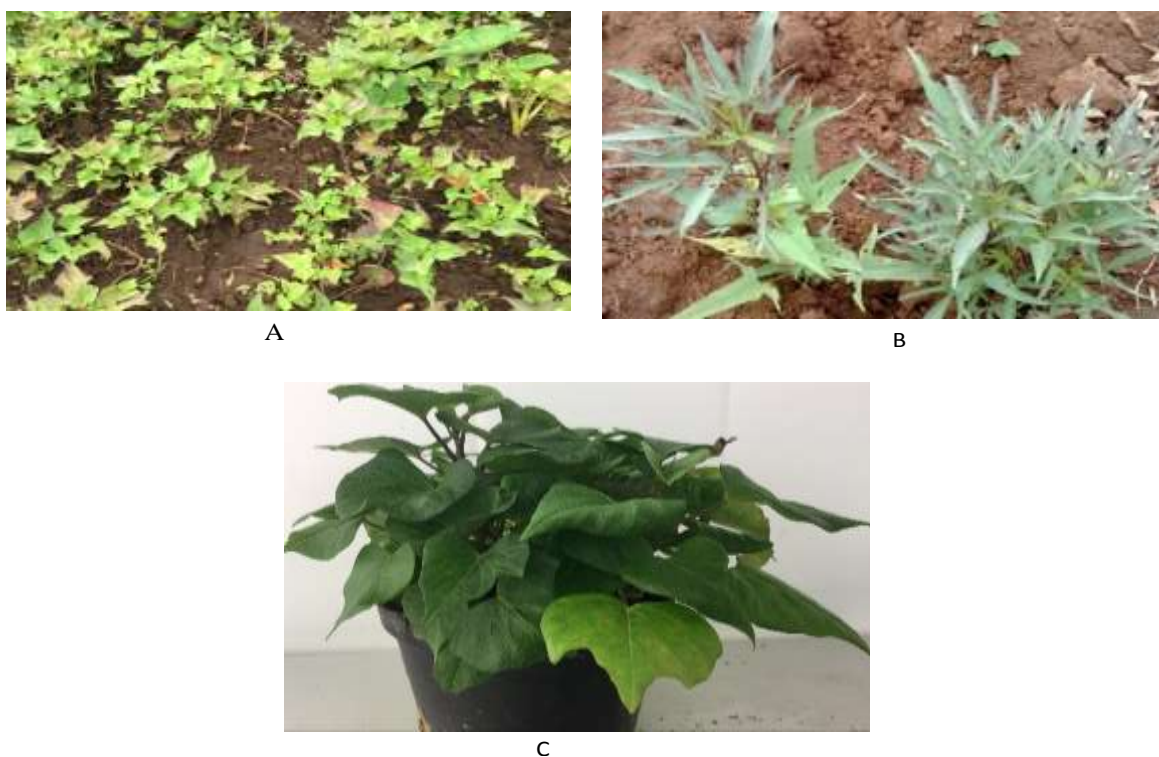


Figure 2. Sweet potato plants with viral disease symptoms in Wolayta zone, southern Ethiopia. (A) Virus like symptoms in farmers field, (B) Mild symptoms of SPFMV infected sweet potato plant ('Kulfo') in the farmer field, (C) Stunted sweet potato plant due to co-infection by SPFMV and SPCSV initially from fields (Photo: D.H. Buko).

show virus-like symptoms. Figure 2B and C respectively, show sweet potato cultivars in fields infected with SPFMV and double infection of SPFMV and SPCSV commonly called SPVD. Indeed, this is the main way in which viruses were introduced and spread from one area to another in African countries such as Uganda (Karyeija et al., 1998). In addition, farmers seldom renew their planting materials, but they keep it for many years by vegetative propagation. Therefore it builds up infection within their fields every year. This planting practice, combined with the fact that many sweet potato viruses

are transmitted by aphids and whiteflies widely distributed in Ethiopia, (Table 3) increases the risk of more severe infections and the establishment of viral disease in neighboring virus-free fields.

Methods of virus elimination and virus-free planting material in Ethiopia

Different virus elimination methods have been developed and applied to produce disease-free clones of

Table 3. Symptoms of common sweet potato viral diseases and vectors involved in their transmission.

Virus	Symptom observed in sweet potato	Ways of transmission	Geographic distribution
SPFMV	Single infection: no clear observable symptoms when it infects alone or only mild circular spot on the older leaves or light green pattern along veins. Feathery, purple pattern in the leaves (Gibson et al., 1997; Ryu et al., 1998). It could vary based on cultivar infected and growth conditions	Via stylet of several aphid species in a non-persistent manner, (Stubbs and McLean, 1958)	Worldwide, Reported in Ethiopia
SPCSV	Single infection: causes slight stunting, purpling of lower leaves, mild chlorotic mottle and yellowing (Gibson et al., 1998; Gibson and Aritua, 2002).	Transmitted by whiteflies in Semi-persistently manner (Sheffield, 1957; Sim et al., 2000)	Worldwide, reported in Ethiopia
SPFMV + SPCSV (SPVD)	Dual infection: Infected plant became stunted and produce small-distorted edges, narrow crinkled, strap like leaves with chlorotic mosaic or vein clearing, purpling of older leaves, chlorosis along main leaf veins (Schaefer and Terry, 1976; Gibson et al., 1998)	See above for individual virus	Worldwide, but severe in Africa Reported in Ethiopia
SPVG	Ranges from symptomless to yellow spotting on the leaves	Aphids	Worldwide, reported in Ethiopia
SPMMV	Symptomless to mild leaf mottling and stunting	May be transmitted by whiteflies to sweet potato (Sheffield, 1957; Hollings et al., 1976)	Burundi, Kenya, Tanzania, Uganda, Philippines
SPVG + SPCSV	Symptomless to purple spots and inter-veinal yellow spots	Aphid (SPVG) and Whitefly (SPCSV)	
SPV2	No information for single infection	Transmitted by Aphid (Moyer et al., 1989)	Worldwide, reported in Ethiopia
SPVC	No information for single infection	Transmitted by Aphid (Moyer et al., 1989)	Worldwide, recently identified in Ethiopia (own unpublished)

SPFMV: Sweet potato feathery mottle virus, SPCSV: Sweet potato chlorotic stunt virus, SPVG: Sweet potato virus G, SPMMV: Sweet potato mild mottle virus, SPVC: Sweet potato virus C. SPVD: Sweet potato virus diseases, SPV2: Sweet potato virus 2

economically important crops around the world. Meristem tip culture and shoot tip culture alone and/or in combination with different therapeutic actions: heat treatment cryotherapy and chemotherapy have been used to eliminate virus from many crops, including sweet potato infecting virus in many countries (Spiegel et al., 1994; Panta et al., 2006; Wang and Valkonen, 2008; Panattoni et al., 2013). These methods have been applied to generate virus-free sweet potato in many countries of the world: Taiwan (Green et al., 1992), United States of America (Clark and Hoy, 1999), China (Feng et al., 2000), many countries in Europe (Wang and Valkonen, 2008) and Japan (Yamasaki et al., 2009). Virus from different plant species (root crops, ornamental crops, and tree) have been eliminated by heat-treating mother plants followed by meristem tip culture (Hakkaart and Quak, 1964).

In general, developing countries in East Africa, including Ethiopia, are seemingly left far behind in the adoption and application of tissue culture techniques for virus elimination. In Ethiopia, few attempts have been

accomplished to develop *in vitro* propagation protocols and use of virus elimination techniques for sweet potato. However, meristem culture and heat treatment have been used and were able to eliminate viruses from three varieties of sweet potato in Ethiopia (Table 4) (Dugassa and Feyissa, 2011). These varieties cleaned of viruses were not made available may be they were not maintained or was done just for the master thesis study purpose. The efficiency of meristem culture and combined heat treatment have also been evaluated and compared (Dugassa and Feyissa, 2011). However, there is no schemes developed and in use to provide virus tested material.

Generating and providing 'virus-free' sweet potato planting materials increases yield per hectare, which improve human food security and livestock fodder. Virus elimination and explant-regeneration requires a good tissue culture protocol. Developing new or adopting and modifying existing protocols previously developed elsewhere in the world important. However, lack of and/or limited laboratory facilities, lack of practically trained

Table 4. List of sweet potato cultivars tested for virus and virus elimination methods used in Ethiopia.

Cultivar/access ions	Elimination methods	Number of clones tested	Elimination efficiency* (%)	Reference	
'Hawassa 83'	Meristem culture	9	100	Dugassa and Feyissa, (2011)	
	Shoot tip thermotherapy	9	88.9		
'Guntute'	Meristem culture	6	100		
'Hawassa local'	Meristem culture	8	100		
	Shoot tip thermotherapy	6	100		
'Bellela'	Meristem culture	24	99.9		
'Temesgen'	Meristem culture	24	100		Wondimu et al.
'LO-323'	Meristem culture	25	100		(2012)
'Zapallo'	Meristem culture	25	100		

*Efficiency of virus elimination methods were determined based on the percentage of virus-free plantlets obtained by each method.

workforce, less access to reagents, absence of functional greenhouses and insect proof screen houses are still considered to be the main challenges to adopt and use the existing techniques in Ethiopia.

Still virus infection high level, planting materials available to farmers are unreliable in terms of viral infection. Therefore, urgent attention and action is in need to increase the yield of sweet potato, mainly by providing clean planting material and measure to reduce re-infection rate. Implementation of integrated strategies that target the prevention of the introduction of virus, their vector, and their distribution into uninfected areas. Such strategies in turn, could enable resource-poor farmers to maintain healthy sweet potato planting materials.

Production challenge due to sweet potato virus call for intervention in Ethiopia

Strong quarantine restrictions

As presented in Table 1, five sweet potato infecting virus species were detected in southern Ethiopia. In addition, six more virus were reported from germplasm imported for improvement works (Shiferaw et al., 2017). To limit further spread of the existing viruses into new production regions, the different key players need to work in synergy. Before distributing planting materials from virus spot location of southern Ethiopia to new locations, healthy status must be first confirmed. In this regard, Research Centers must apply rigorous quarantine checks. The technical guidelines for the exchange of pathogen-free sweet potato plant materials should be followed (Moyer et al., 1989). Both exporting and importing bodies ought to abide by these guidelines.

Screening and breeding for resistance

In Ethiopia, cultivar diversity is getting lost due to low

yielding and infection of viral diseases. This is true particularly in the virus-prone areas of SNNPR where one of the improved variety called Hawassaa-83 dominantly grown. It is possible to screen virus tolerant sweet potato cultivars from local cultivars and use them for resistance breeding. Experts in Agricultural Research Centers in Ethiopia have been trying for a long time to screen and use disease tolerant varieties. The effort to solve the problem appears not yet to be successful, thus, the yielding potential of sweet potato cultivars is declining. Though it needs further effort, Shiferaw et al. (2017) reported of promising accessions for virus resistance. As presented earlier in the paper, the efforts to screen for disease resistance and better yield in southern Ethiopia was not without the risk of introducing viruses along with germplasm. It is advisable to exploit local cultivar gene pools in the country instead of introducing infected material as quarantine restriction of the country is not strong enough to screen out.

Therefore, it appears that no adequate and appropriate interventions were made in screening and breeding for disease resistances in sweet potato and it needs a more coordinated effort of all stakeholders. Exploiting resistant genotypes from germplasm pools using both traditional and recent advanced molecular methods would be important.

Training

Sweet potato growing farmers and extension workers in Ethiopia have low perceptions of viral diseases (own, unpublished data). Inabilities to identify a virus-infected plant based on symptoms in the field and lacking basic know-how on its mechanisms of transmission affects proper selection of healthy looking plating materials. Moreover, it contributes to the continuous use and exchange of infected planting materials from season to season. Therefore, training basic practices on disease

identification and management is very important. Moreover, training that enable farmers selecting and using of good planting materials and how to practice sanitation measures would be vital.

Naturally virus resistant/tolerant cultivars, show no symptom depending on many factors. If the farmers do not have access to virus-tested planting materials, and still have to grow it, training would help them to select the best mother plants from the existing symptomless plants (with possible low concentration of virus titers or healthy) in their farm. Farmers' training on removing weeds that may harbor virus-transmitting insects is vital. In additions, weeds may serve as an alternative host for the viruses, must be removed on time. Educating farmers how to identify and rouging out infected plants, proper and timely application of sanitation practices and crop management is very important.

Farmers' closer mentors have high impacts in improving agricultural practices. Study conducted in Ethiopia shows extension workers in the studied areas were less exposed to training on sweet potato diseases identification and management (own unpublished data). It is important to provide problem-solving practical training to those who work closely with farmers. Extension workers should get awareness and training on the sources and choice of good planting materials (diseases free, high yielding), the negative effects of sweet potato viral diseases, practical virus identification in the field and knowhow of appropriate disease management principles. In general, training will greatly contribute to proper virus management that results in the higher chance of reducing the infection of new areas and improves the yield of crops. Training should include practicing sanitation measures in the field, removing infected plants timely to avoid virus spreads within plants and avoiding contamination of pathogen-tested planting materials.

Technical capacity building and laboratory facility

Expertise and basic laboratories are required for diagnosis, identification, and elimination of viruses. Without proper knowledge, it is more difficult to manage virus diseases. There are limited numbers of professionals and poor laboratory facilities in developing countries in general, both for virus diagnosis and elimination. In Ethiopia, there are very limited numbers of experienced plant virologists. Moreover, they have limited access to practically oriented training on identification and elimination of plant viruses, mainly because of a lack of access to properly equipped laboratories and reagents, both at the regional and national levels. This may have Even though virus elimination techniques have been developed and largely utilized across the world, they are less used in Ethiopia. Because of poor facility and technical problem, farmers in Ethiopia have no access to virus-tested planting materials. As a result, farmers

continue to use virus-infected vegetatively propagated sweet potato planting materials that could build up over years. Therefore, availability of basic facilities and technically skilled professionals is important to develop/adopt effective methods and establish programs to develop and maintain pathogen tested propagation stocks of farmers preferred root crop cultivars.

This calls for collective and individual roles of all key-players including the government, Non-Governmental Organisation (NGOs), private sectors, research institutions, Ministry of Agriculture and universities in funding for laboratories and capacity building. Universities and research institutions should be more involved in training extension workers, farmers and other stakeholders. The government should play a major role in allocating funds for laboratory facilities and research activities. Researchers are expected to conduct studies and know the virus species associated with farmers preferred varieties in all the production regions. They should also work to design methods adapted to local conditions and evaluate the best virus elimination and subsequent management methods for the respective viruses.

Provision of virus-tested planting materials

Availability of disease-tested planting materials with desired agronomic traits is key to increase production and thereby improving the life of the farmers. Virus-tested materials can be obtained either through screening naturally existing plant materials or by eliminating viruses from mother plants. Very little progress has been made to identify and eliminate virus from vegetatively propagated materials in Ethiopia. There are no big companies certified to supply virus tested sweet potato planting materials, except for some recent practices of using tissue-cultured plants as a starter. Further multiplication in open fields makes the plants prone to re-infection before reaching the farmers. Moreover, these small-scale multipliers are not getting basic clean starting materials and have no rigorous follow up. In multiplier fields, viruses can also get multiplied and when distributed to farmers, it transmitted to the susceptible host in the nearby field and infect sweet potato landraces on farmer's hands. Therefore, a short-term solution to tackle the problem is to intervene through the provision of vines of pathogen-tested sweet potato plants to the farmers and giving awareness on subsequent management practices to reduce the infestation rate. The use of clean and virus-tested planting materials is economically viable if there is an effective and efficient system for production, multiplication, and distribution of planting materials (Carey et al., 1997; Feng et al., 2000).

What intervention is needed? Providing clean planting

materials of root and tuber crops boosts yield and farmer's income. Therefore, all stakeholders (Government, NGOs, Research centers and Universities) are advised to give attention and acknowledge the necessity to provide resources for virus assessment and elimination. The private sector should be encouraged to collaborate with the universities and research centres and invest on tissue culture facilities for commercial production of healthy and quality vines. Initiating new ideas of investment in tissue culture and strengthening existing institutions and farmers' associations to propagate virus-tested plant is a priority. In addition, extension officers should contribute to demonstrate that the use of clean/symptomless planting materials would consistently produce higher storage root yield than the naturally infected farmers' planting materials.

CONCLUSION AND RECOMMENDATIONS

Surveys on sweet potato viral diseases in Ethiopia revealed that viral disease incidence and severity is a critical issue for sweet potato production in the southern region of Ethiopia. National germplasm collection and farmers' fields are contaminated with the most common sweet potato viruses; SPFMV, and SPCSV. As a result, the rate of spread and its negative impact on the yield is discouraging farmers who grow and use sweet potato as a main food security crop. The Southern Nations Nationalities and Peoples Regional State is the National Center and the source for a further introduction of sweet potato plant materials to other parts of the country. Therefore, this current incidence of sweet potato virus in this region will be a potential threat to sweet potato production in the whole country. Collectively, this demands intervention at all levels (that is, both at institutions and farmers' levels). Moreover, new viruses are being introduced with germplasm from international sources. Therefore, in order to reduce the negative impacts of viruses on yield of sweet potato in Ethiopia, the following points are recommended and need attention.

- (i) Organizing and the strengthening of the quarantine systems during importation to the country and certification of planting materials movement between regions is very important.
- (ii) Germplasm introduction should be regulated and new materials should be inspected prior to introduction and multiplication in the open fields.
- (iii) Standardized method for large scale virus detection in Ethiopia.
- (iv) Future virus surveys should address more production regions in the country and use appropriate testing methods.
- (v) Increase awareness of viruses to farmers and

extension workers.

- (vi) Supplying virus-tested planting materials and establishing a system of distribution would enhance the farmers' ability to increase production and productivity of sweet potato.

FUNDING

This work was supported by the NORAD funded project "Controlling disease in sweet potato and enset in South Sudan and Ethiopia to improve productivity and livelihoods under changing climatic conditions using modern technologies" under the NORHED program (agreement no ETH-13/0017, 2013).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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