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Review

Importance, biology, epidemiology, and management of *Xanthomonas campestris* pv. *musacearum* (*Xcm*) of Enset [*Ensete ventricosum* (Welw.) Cheesman] in Ethiopia

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ABSTRACT

Enset [*Ensete ventricosum* (Welw.) Cheesman] is an economically, nutritionally, and industrially important root crop in Ethiopia. However, many biotic and abiotic factors are negatively affecting and reducing the production and productivity of the crop in Ethiopia and elsewhere. Of the various bacterial plant diseases limiting enset productivity, bacterial wilt caused by *Xanthomonas campestris* pv. *musacearum* is one of the major cosmopolitan and destructive pathogens in all enset-growing areas. This piece of work was undertaken to: 1) review the economic importance and ecological requirements of enset and the extent of total yield loss due to *Xcm*; 2) review the biology and ecological requirements of the pathogen leading to epidemics; and 3) compile the management options for sustainable enset production and productivity. This review highlights various studies on the importance of the disease and the efforts employed so far in the management of this highly destructive disease to enset production. To achieve these objectives, data and information were gleaned from different sources of journals, theses, books, proceedings and symposium papers, relevant compendia, internet resources and personal communications. From the review insight, it is confirmed that there is no single best enset wilt management option available that farmers rely on and there is a lack of resistant varieties. Cultural and sanitary measures are the only methods most frequently used across the enset-growing areas and are found to be fruitful in community mobilization to create awareness among the farming community. In the future, awareness creation and regular field monitoring are vital, while the development of resistant or tolerant varieties is mandatory.

Keywords: Bacterial vascular wilt, corm, prevalence, pseudo stem, severity, sucker, variety, yield loss.

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INTRODUCTION

Enset [*Ensete ventricosum* (Welw.) Cheesman] is a type of monocarpic, perennial, herbaceous crop of the Musaceae family. It is thought that enset was domesticated in Ethiopia about 10,000 years ago (Brandt *et al.*, 1997). It has a banana-like appearance, but it is taller, fatter, and lacks edible fruits, earning it the name "false banana". Enset is propagated by vegetative propagules. Suckers emerge from an underground rhizome (corm) and a bundle of leaf sheaths creates the pseudostem and big leaves. The sucker matures into a new fruit-bearing plant over time. Enset grows up to 13 meters tall and the pseudostem can be as thick as one meter in diameter, making it larger than a banana plant (Buzunesh, 1984; Brandt et al., 1997).

Enset is cultivated at elevations ranging from 1200 to 3100 meters above sea level with average annual rainfall requirements ranging from 1100 to 1500 mm, temperatures ranging from 10 to 22°C, and relative humidity ranging from 63 to 80% in most enset-growing locations. Moderately acidic to alkaline soil with a pH of 5.6 to 7.3 are good or optimum for enset growing (Bezuneh and Feleke, 1966; Addis, 2005).

Enset has been traditionally ranked first as a planted staple food crop in the highlands of central, south, and southwestern Ethiopia, and it is cultivated as a food security crop, source of nutrition, and generation of revenue. *Kocho, bulla*, and *amicho* are the most common traditional food products prepared from enset. The major food product, *kocho*, is prepared by fermenting a mixture of scraped pulp from the pseudostem, pulverized corm, and inflorescence stalk. The average *kocho* per plot yield is relatively low in the cold wet mid-altitude zones above 3000 meters above sea level and warm sub-humid lowlands below 1900 meters above sea level while the highest yield is produced in the humid to mid-highland zones between 2000 and 3000 meters above sea level (Sahle et al., 2018). The corm can be harvested at almost any stage during the growing season. The energy yield of enset is significantly more than that of several bowls of cereals as well as potatoes, sweet potato, and banana (Pijls et al., 1995).

In the 2020 cropping year, 157,705,763 enset trees were harvested across enset-growing regions in Ethiopia. As a result, the total output in *amicho, kocho*, and *Bula* was approximately 4,408,830.98; 4,894,387.77; and 147,503.96 metric tons (Mt.), respectively (CSA, 2021). In the southern and southwestern parts of the country, enset provides human food, animal feed, fiber, construction materials, and pharmaceuticals to more than 20% of Ethiopia's population (Azerefegne et al., 2009; Borrell et al., 2019). According to Garedew and Ayiza (2018), more than 15 million individuals use enset crop as a staple meal in mixed subsistence farming systems. The crop is commonly produced alongside coffee, multi-purpose trees and along with annual food and fodder crops in mixed agricultural systems. Enset is an outlay crop that also offers or provides animal feed, used as local building/construction material, as fire fuel, and traditional herbal medicine (Tsehaye and Kebebew, 2006). According to research conducted by Tsegaye and Struik (2001), Ethiopia's enset-growing locations are known for their high population density per square kilometer, and cannot be supported by any other land use or food security crop.

Drought, heavy rainfall, flooding, and other environmental variables have little effect on the enset crop plants. As a result, the crop has the potential to aid national efforts to ensure availability, food security, and self-sufficiency or reliability (Tsegaye and Struik, 2002; Negash and Niehof, 2004). Despite its importance, the crop is rapidly losing ground as a reliable crop due to biotic and abiotic causes. According to reports by various authors, bacterial wilt (Yirgou and Brandbury, 1968), bacterial corm rot (Quimio and Tesera, 1996; Brandt et al., 1997), and bacterial sheath rot (Quimio, 1992) are the commonly known enset bacterial diseases. The principal limitation that is economically relevant and that threatens the enset-based agricultural system has been the enset bacterial wilt that is caused by *Xanthomonas campestris* pv. *musacearum,* and which was initially reported and described first by Yirgou and Brandbury (1968) and later by Shank and Cherenet (1996). In the southwestern Ethiopian province of Kaffa, natural epidemic disease was reported on the banana cultivar cv. Ducasse (Yirgou and Bradbury, 1974).

In Ethiopia, except few farmers majority of them do not know the mechanisms of survival of the pathogen, how it infects the host plant, what factors favor the disease/pathogen and lead to epidemics over time, space and how to against it for sustainable enset production and productivity. Fully comprehensive research information on enset bacterial wilt is also limited for references by stakeholders because it received little research attention due to its nature known as an orphan commodity. Hence, reviewing and compiling appropriate aspects of enset bacterial wilt and the causal pathogenic agent is of paramount importance. Therefore, this article paper was aimed at reviewing previous works and compiling literature data to provide information and knowledge on the importance, biology, epidemiology, and management of bacterial wilt due to *Xanthomonas campestris* pv*. musacearum* (*Xcm*) of enset [*Ensete ventricosum* (Welw.) Cheesman] in Ethiopia.

Thus, the general objective of this work was the assessment of published research articles and professional books on enset bacterial wilt, and available management options in the last few years, with a focus on Ethiopia, with the prime intention of provision of information, research data, and knowledge to researchers, students, policymakers, end-user farmers and other stakeholders.

The specific objectives of the review paper were to: 1) identify the biological and ecological prerequisites for long-term enset production; 2) review the economic significance of enset bacterial wilt in Ethiopia and other parts of the world; 3) compile the biology of the bacterial will-causing *Xanthomonas campestris* pv. *musacearum*; and 4) review the environmental conditions that favor *Xanthomonas campestris* pv. *musacearum,* which could lead to epidemics, as well as potential management solutions to enset bacterial wilt.

Various sources of information were reviewed and analyzed. Different pieces of literature and journals including Elsevier and Springer were also reviewed. For this review paper, secondary source of data, data and information from scientific journal publications, PhD dissertations, Master's thesis, research reports, books and book chapters, proceedings and symposium papers, relevant compendia, internet resources, personal communications, and similar other resources were gleaned.

BIOLOGY, TAXONOMY, AND ECOLOGICAL REQUIREMENTS AND PRODUCTION OF ENSET *(ENSETE VENTRICOSUM* L.)

Biology and origin of *enset* [*Ensete ventricosum* (Welw,) Cheesman]

Leaves, pseudostems, subsurface corms, and adventitious roots are all part of the enset plant. Enset can grow up to 13 meters tall with a 1-meter diameter (Birmeta et al., 2002). The edible component of enset, unlike bananas that provide fruits/fingers, is made from the pseudostem and underground corm rather than fruits. Enset, like its wild cousin (bananas), is a diploid species (2n = 18) (Cheesman, 1947). The enset genus, *Ensete*, which belongs to the Musaceae family, has numerous botanical similarities to its near relative, banana.

Taxonomic description of enset (*Ensete ventricosum*)

Domain: Eukaryota
Kingdom: Plantae
Phylum: Spermatophyta
Subphylum: Angiospermae
Class: Monocotyledonae
Order: Zingiberales
Family: Musaceae
Genus: Ensete
Species: Ventricosum

Enset is known by its preferred scientific name, *Ensete ventricosum* (Welw.) Cheesman, and the preferred common name, Abyssinian banana. *Ensete edule* Bruce ex. Horan, *Musa arnoldiana* De Wild, *Musa ensete* J.F. Gmel, and *Musa ventricosa Welw* are the other scientific names. *E. superbuni* and *E. glnucuni* are two commonly recognized ensete species that grow wild in Asia, *E. perrieri* in Madagascar, *E. gilletii, E. homblei,* and *E. ventricosum* in eastern Africa (Simmonds, 1962).

Some enset species have been found to grow in North America (Cheesman, 1947). In Ethiopia, *Ensete ventricosum* is thought to be the only wild species (Simoons, 1956). *Ensete ventricosum* was historically only grown in Ethiopia's south and southwestern regions, but due to recurrent droughts, enset cultivation has spread to other parts of the country (Birmeta et al., 2004).

Enset (*Ensete ventricosum*) is a perennial monocarpic crop that, like bananas, belongs to the Kingdom Plantae, Order Zingiberales, and the family Musaceae. Musaceae is a monocotyledonous flowering plant family. The family is native to Africa and Asia's tropics, and it consists of two genera, *Musa* and *Ensete*, each consisting of roughly over 50 species. They are mostly grown for different purposes, specifically, banana for its fruit and enset is grown for its fibers, manila, and hemp that are used to make rope and serve as food for human beings and animal feed. They are also used as decorative plants. Enset is Ethiopia's most important root crop and a traditional staple food in the country's densely populated southern and southwestern parts (Birmeta et al., 2004). Enset is a perennial herbaceous crop belonging to the Musaceae family (Cheesman, 1947). The shapes of enset and banana plants are similar; however, the enset plant is larger and thicker than the banana plant. That is, enset (*Ensete ventricosum*) is a banana-like plant that produces a single corm in the underground and a pseudostem aboveground (Brandt et al., 1997).

Cheesman (1947) and Moore (1957) botanically distinguished the two Musaceae genera, *Musa* and *Ensete*. Baker and Simmonds (1953) provided a detailed description of the *Ensete* species. According to Vavilov (1951) and Simmonds (1958), Ethiopia is one of the primary centers of origin and diversity for several kinds of cereal (barley, durum wheat, tef) as well as various pulses, oil crops, stimulants (*Coffea arabica, Catha edulis*) and enset (*Enset ventricosum*).

The seedy leathery fruits of the enset plant, unlike the domesticated bananas, are inedible. The genus *Ensete* consists of diploid species with n = 9 (Yemataw et al., 2012). *Musa* species with n=10, 11, or 14 have varied ploidy levels (diploid, triploid, and tetraploid). *Ensete* and *Musa* both feature a big underground corm, a pseudostem (a bundle of leaf sheaths), and large, paddle-shaped leaves. The meristem zone lies near the soil surface, where the pseudostem and subsurface corm meet. Even though *Ensete* is thicker and larger than banana, anatomically, reaching heights of up to 13 meters and a diameter of more than 1 meter, both enset and banana are herbaceous perennial monocarpic crops that produce flowers just once during their life cycle (Endale, 1997). New suckers emerge from preexisting buds in the corm when a banana plant dies. Sucker production is triggered only when the meristem is injured in enset, on the other hand for enset, the corm, pseudostem, and leaf petioles are the main sources of food, while for bananas, the fruit is the main source of food (Hildebrand, 2001).

Ecological requirements of enset

The best conditions for enset cultivation are found between 2,000 and 2,750 meters above sea level with 1100 to 1500 mm of rainfall, a temperature range of 10 to 21°C, and relative humidity of 63 to 80% (Brandt et al., 1997). Although enset may grow in a variety of climates, it prefers acidic, heavy clay soils that retain a lot of organic matter when manured (Shank, 1994; Tsegaye, 2002; Birmeta et al., 2004).

The domesticated enset is cultivated at elevations ranging from 1,200 to 3,100 meters above sea level. It grows best between 2,000 and 2,750 meters above sea level. The majority of the rainfall days fall between March and September in most enset-growing locations in Ethiopia, with annual rainfall ranging between 1,100 and 1,500 mm. Enset growing areas have an average temperature of 10 to 21°C and relative humidity of 63 to 80%. Enset is not a fan of the cold. Above 2,800 meters above sea level, frost damage to higher leaves is prevalent, and major stunting is common above 3,000 meters above sea level (Brandt et al., 1997). The constraint on enset plant growth below 1,500 meters is most likely due to the lack of available water rather than due to high temperatures. Because of the increased evaporative demand, the overall rainfall and the length of the rainy season decrease in most areas of Ethiopia below 1,500 meters, and the potential water usage by plants increases. The majority of enset crops are grown below 1,500 meters above sea level and require supplemental irrigation or demand small enough to be irrigated with home effluent (Tsegaye and Struik, 2001). Enset was traditionally only grown in Ethiopia's south and southwestern regions, but due to frequent droughts, enset cultivation has spread to other parts of the nation (Birmeta et al., 2004).

Economic importance of enset in Ethiopia

According to Belehu (1996), enset has a wide range of uses with every component of the plant being used for different purposes in Ethiopia. Every part of the enset plant is utilized not only for food but also for different nonfood purposes (Figure 1). According to Gebresenbet (2012), the plant is used to reduce soil erosion, as an attractive and aesthetic plant, and to wrap bread during baking. Brandt et al. (1997) and Shigeta (1996) reported multiple usages of the enset plant, mainly in food and cultural applications in the southwestern parts of Ethiopia. All of these reports demonstrate the vital role of enset in the socio-economic livelihoods of many ethnic groups living in enset-growing areas.

In Ethiopia, enset is playing a crucial role in the farmers' livelihoods. Because the prominent fact is that enset is the primary source of food, livelihood, and animal feed throughout the year (Figure 1). It is also the family's source of revenue as well as a symbol of richness (wealth) and social status. Around houses, a large number of enset plants provide comfort and shade, and some crops, such as coffee, are benefitted since they require medium sunlight only under enset shade (Shigeta, 1990). Because the plant has large leaves and the pseudostem stores a lot of water, most portions of enset plants are suitable to feed domestic animals. In sheep production, feeding different portions of enset as a component or alone, as well as supplementing with a legume, has been shown to aid in body weight gain during dry periods (Nurfeta et al., 2008).

According to Bekele and Reddy (2015), some enset types are thought to have medicinal potential and are used by the enset-cultivated community, and their roots are used as a traditional medicine to treat malady conditions, like stomach pain and amoebic dysentery. In the Areka area, an enset cultivar named 'Sweete' is suggested specifically for treating a person with a bone malady condition (Tadessa and Shigeta, 2016). This could be due to the high calcium and phosphorus contents in enset food. Traditionally, '*bulla*' is fed to mothers who give birth to babies for strengthening and quick maternal recovery in the central highlands and cities where enset is not a staple food. Women also prepare gruel (*muq*) and give it to people who are sick to alleviate their ailments. Negash (2001) stated, in his Ph.D. dissertation, that farmers in the Keffa Sheka Zone believe that some of the Enset clones have medicinal and ritual properties. Choro clone is provided to a woman quickly after giving birth to a baby to encourage the placenta's discharge (Tesfaye and Kebede 2006; Assefa and Fitamo, 2016). With reference to the ritual significance, Keffa farmers believe that planting this clone in their garden drives away the devil or evil spirits, while the *bulla* or corm of Tayo clones is consumed for the treatment of bone fractures, backaches, and swelling due to displacement of joints. When a person gets flu, the corm of Ariko clone is boiled and fed, and children consume its uncooked stem to stay well and produce or increase weight in Keffa. However, the scientific clinical trials of these enset medicinal uses have not been verified or not documented. Probably because of its high carbohydrate content, its potential use as a glucose source has been considered. Farmers' choice of corm (*amicho*) reflects their traditional understanding of its superior nutritional content (Tadessa and Shigeta, 2016).

For *kocho*, *bulla*, cheese, butter, and chat (*Catha edulis*) handling, fresh leaves and dried leaf sheaths are used as packaging materials. In house and traditional restaurants, the enset leaves are also utilized as a dishing tool. The fiber from enset is used to make bags, ropes, twine, cordage, various mats, and fitting or tightening water pipe connections by avoiding trickling. The enset fiber serves as a common traditional construction material for fences and local homes. Sack and string industries also use fiber as raw materials for various purposes. *Bulla* starch is used in the paper and textile industries as a source of raw materials. According to the report of Wondimu et al. (2014), enset (*warqee*) starch can potentially be utilized as a substitute for starch in the pharmaceutical industry. Generally and because of

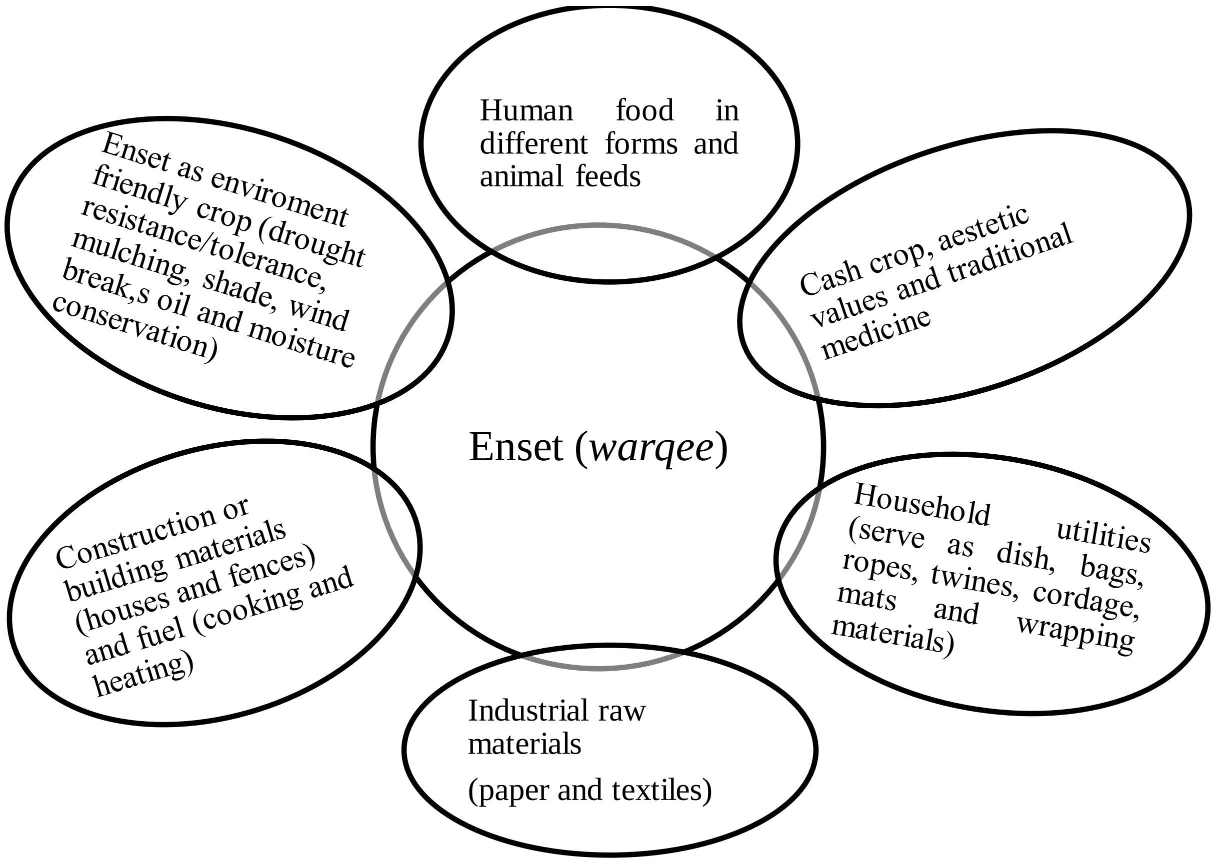

Figure 1. Benefits of enset (*Ensete ventricosum*).

the above-mentioned evidence, enset (*warqee*) is a golden plant, as its name implies, because all of its parts have versatile and have environmental and social-economic values.

Production of enset in Ethiopia

Various historical ideas exist regarding the origins and patterns of enset domestication in Ethiopia's early years (Brandt et al., 1997). Enset is common in Asia, Sub-Saharan Africa (SSA), and Madagascar (Baker and Simmonds, 1953; Simmonds, 1958), but it was only domesticated in Ethiopia about 10,000 years ago (Brandt et al., 1997). Priests' earliest written evidence from 1590 stated that Oromo peasants in the Blue Nile River's southern side grew enset for food (Alula, 1996). Enset is an Ethiopian endemic plant with widely distributed edible root crops in the country's south and southwestern parts. Hundreds of enset rootstocks can be found in both climatic and agro-ecological environments. Following World War II, the Ethiopian Ministry of Agriculture designated enset as a national product within the national research system to emphasize enset research (Brandt et al., 1997). Ethiopia currently has two big collections of domesticated enset field locations. Areka Agricultural Research Centre field station under Southern Agricultural Research Institute (SARI) holds approximately 600 landraces collected from regions where enset has been grown (Borrell et al., 2019). The second is a newer site of Wolkite University that maintains approximately 110 landraces in the Gurage Zone even though the landraces they contain are not publicly available.

In Ethiopia's highly populated southern and southwestern regions, the enset-based farming system has continued to dominate agricultural systems despite the presence of other crops and livestock. According to Shumbulo et al. (2012), enset cultivation covers 6,700,000 hectares in Ethiopia. According to enset production experiments conducted in southern Ethiopia, unsqueezed *kocho* yields ranged from 0.008 to 0.07 tons per plant, with an average of 0.03 tons per plant (Shumbulo et al., 2012; Sahle et al., 2018). Around the Wabe Shebele River catchment area, the average annual yield of unsqueezed *kocho* was estimated to be 6.7 tons per hectare (Sahle et al., 2018).

The quick decline of enset production in northern Ethiopia is not widely documented, but plant diseases, drought, and socio-political events from the mid-18th to mid-19th centuries all played a significant negative role in reducing enset production and productivity (Brandt et al., 1997).

Production constraints of enset in Ethiopia

Several biotic and abiotic factors affect the quantity and quality of enset production. Land scarcity, plant diseases, and insect pests; lack of improved clones with high yields, disease and insect resistance, and drought tolerance; labor scarcity; lack of improved processing and storage technologies; traditional agronomic practices; and the crop's long-term maturity (perennial) behavior; and food insecurity are all major challenges in enset production (Shumbulo et al., 2012; Teshome, 2016). Diseases caused by bacterial wilt, root-knot nematodes (*Meloidogyne* spp.) and lesion nematodes (*Pratylenchus* spp.), mammals, and sucking insect pests, such as mealybugs (Table 1), have all been recognized as major biotic constraints (Tadessa and Shigeta, 2016; Belachew and Aklilu, 2018). Enset bacterial wilt is known to be an important and major disease affecting enset production and productivity in Ethiopia (Tewodros and Tesfaye, 2014; Tadessa and Shigeta, 2016; Teshome, 2016; Adanech, 2017).

Table 1. Most frequently reported enset production constraints in Southern Nations, Nationalities, and People's Region (SNNPR) of Ethiopia.

Major constraints in enset production	As reported by the percentage (%) of farmers
Corm rot	52.8
Porcupine	52.2
Enset *Xanthomonas* wilt	35.9
Enset root mealybug	34.6
Mole rat	24.7
Leafhopper	19.5
Pig/wild hog/ swine	12.4
Drought	8.0

Sources: Adanech (2017) and Yemata (2018).

ENSET BACTERIAL WILT DISEASE

Overview

Enset bacterial wilt is a disease that was first reported in Ethiopia in 1930 (Castellani, 1939) and was first described as bacterial wilt on enset in Ethiopia in 1968 (Yirgou and Brandbury, 1968) and later on banana (Yirgou and Bradbury, 1974) based on observations. The disease was contained in Ethiopia until the first occurrence in Uganda in 2001 (Tushemereirwe et al., 2004), the Democratic Republic of Congo (Ndungo et al., 2006), Burundi, Kenya, Rwanda, and Tanzania (Tushemereiwe et al., 2006; Carter et al., 2010).

The spread of bacterial wilt disease has become the most significant constraint to enset output in Ethiopia and banana production in East Africa (Blomme et al., 2017). Enset bacterial wilt has emerged as Ethiopia's most important, prevalent, and non-discriminatory disease, capable of incurring yield losses of up to 100% (Tariku et al., 2015; Yemataw et al., 2016). In the early 1960s, a new outbreak of the causative agent occurred in different enset and banana-growing areas in Ethiopia's southwestern region (Yirgou and Bradbury, 1974). The disease did not initially attract much attention, because the incidence/severity was not as severe as it is now. Since the 1980s, reports emerged indicating that the disease is becoming a major challenge to enset production in all enset-growing areas and it is now recognized as a significant disease affecting enset production. Bacterial wilt has adapted into Ethiopia's most devastating ancient disease, attacking on-site at any stage of growth and becoming an economically significant disease across all enset-growing areas (Yemataw et al., 2016; Adanech, 2017; Yemataw, 2018).

Economic importance of bacterial wilt of enset

The most serious biological problem for enset production is plant disease, which is caused by various bacteria, fungi, viruses, and nematodes (Wolde et al., 2016). The most important constraint to enset production today is the bacterial wilt of enset which is caused by *Xanthomonas campestris* pv. *musacearum* (*Xcm*) (Yirgou and Brandbury, 1968; Wondimagegne, 1981; Quimio and Tesera, 1996; Brandt et al., 1997; Welde-Michael, 2000). The most economically significant constraint is bacterial wilt disease, which puts the sustainability of enset farming systems in jeopardy (Shank and Cherenet, 1996). The yield loss can approach 100% when it causes full wilting (Brandt et al., 1997; Wolde et al., 2016). According to Desalegn and Addis (2015), the incidence rate of enset bacterial wilt is equal to the stand loss percentage since the infected plant will not recover and the community will not use the diseased plant for any other use. The bacterial wilt of bananas has harmed household and national food security and income (Tushemereirwe et al., 2003, 2004).

The bacterial wilt causes up to 100% yield loss, especially in ABB genotype bananas, and non-discriminating infection of all *Musa* cultivars in Africa (Ssekiwoko et al., 2006), seriously jeopardizes food security and livelihoods for banana-based agricultural communities (Tushemereirwe et al., 2003, 2004; Kagezi et al., 2006; Ssekiwoko et al., 2006). The loss of the mother plant, which would otherwise contribute to the ratoon plant's production cycles, has an economic impact (Tripathi et al., 2007). Due to soil-borne inoculum carryover, farms infected with *X. campestris* pv. *musacearum* cannot be replanted with bananas or enset for at least six months (Biruma et al., 2007).

Over a decade, East Africa has reported economic losses in the range of $2 to 8 billion because of banana *Xanthomonas* wilt (Tripathi et al., 2009; Nkuba et al., 2015). Regrettably, managing infections caused by banana *Xanthomonas* wilt pathogens is very tough (Eden-Green, 2004). *Xanthomonas campestris* pv. *musacearum* (*Xcm*) is anticipated to be a continuous problem in East and Central Africa due to the lack of consistent application of recommended management strategies (Shimwela et al., 2016) and no resistant source in *Musa* germplasm is available (Tripathi et al., 2017).

Causal agent of enset bacterial wilt

Xanthomonas campestris pv *musacearum* cause disease enset bacterial wilt. There are 420 species and hundreds of pathovars of Gram-negative, rod-shaped, and plant-pathogenic bacteria in the genus *Xanthomonas*, which belongs to the class Gamma Proteobacteria. Because of the pigment xanthophyll and the exopolysaccharide xanthan, most *Xanthomonas* species produce yellow mucoid smooth colonies (Vauterin et al., 1995).

The genus *Xanthomonas* affects at least 44 plant families, including some commercially important ones, such as Solanaceae, Leguminosae, and Zingiberaceae (Biruma et al., 2007). *Xanthomonas musaceae* (Yirgou and Brandbury, 1968) was the pathogen's initial name, but it was then renamed *Xanthomonas campestris* pv. *musaceae* (Yirgou and Bradbury, 1974; Young et al., 1978). It is a genetically highly monomorphic pathogen of perennial banana and enset crops, with no known diversity among currently studied isolates. Whole-genome sequencing revealed 272 SNPs amongst a small collection of 13 isolates from seven East and Central African countries that showed identical profiles. A report by Aritua et al. (2008) indicated that homogeneous strains of *Xanthomonas campestris* pv. *musaceae* are very similar to *Xanthomonas vasicola* strains from maize, sorghum, and sugarcane and proposed a new pathovar of the species *Xanthomonas vasicola* pv. *musaceae* based on biochemical and genomic sequence analysis, but this was not accepted. However, a later study suggested analysis that is, more molecular and validation (Studholme *et al*., 2019).

The only known major natural hosts are bananas and enset. Sweet potatoes, sugarcane, maize, common beans, and sorghum are among the many hosts infected by *Xanthomonas* species (Nakato et al., 2018). According to Chala et al. (2016), *Xanthomonas campestris* pv. *musacearum* has been also found to utilize maize, sorghum, finger millet, and *canna* species as alternate hosts.

Xanthomonas campestris pv. *musacearum (Xcm)* of Enset [*Ensete ventricosum* (Welw) Cheesman]

The pathogen *Xanthomonas campestris* pv.*musacearum* causes wilt of enset. *Xanthomonas* was first discovered on enset in Ethiopia in the 1930s (Castellani, 1939), but not until 1968 (Yirgou and Brandbury, 1968) it was identified as *X. campestris* pv. *musacearum* on enset, and then on banana in 1974 (Yirgou and Bradbury, 1974). Leaf yellowing, twisting, wilting/collapsing, and pockets of yellow or cream-colored slimy ooze seen in cut vascular tissues in leaf sheaths, leaf midribs, and stems are all symptoms of the disease (Blomme et al., 2017).

The darkening of enset vascular bundles is common, although not as noticeable as the interior discoloration seen in bananas. When the disease takes hold, total yield loss is expected, but tolerant cultivars, such as "Mazia," "Badadeti," and 'Astara" have been shown to recover (Tariku et al., 2015). *Xanthomonas* wilt of enset is disseminated primarily through contaminated planting materials and cultivation and processing tools. Porcupines (*jart*), warthogs (*kerkero*), and mole rats (*filfel*) that frequently consume corms spread Xanthomonas wilt of enset (Brandt et al., 1997).

Because plants are harvested before or at flower emergence, insect vector transmission via flowers does not occur in cultivated enset. It is unknown how common *Xanthomonas* wilt of enset occurs in the wild enset. More widely, the pathogen first appeared in Uganda and the Eastern Democratic Republic of Congo in 2001 and has been expanding since then across much of East and Central Africa's highland banana production zones, owing to a disease reservoir in enset (Blomme et al., 2017). Disinfecting instruments between uses on different plants, keeping animals away from browsing contaminated plants, fencing infected places, and removing contaminated plants rigorously, all are management techniques that could prevent, restrict, or eliminate the spread of *Xanthomonas* wilt of enset (Quimio and Tesera, 1996). According to Nakato et al. (2018), a concurrent genomic study on *X. campestris* pv. *musacearum* has identified evidence of two separate section ages, implying more than one introductory event and putative virulence genes that may facilitate host infection.

Symptoms of enset bacterial wilt

Both banana and enset bacterial wilt symptoms include yellowing of leaves, wilting (frequently coupled with the loss of turgor and collapse of the petiole), and the secretion of yellowish bacterial oozes (exudate) from cut tissues (Thwaites, 2000; Tushemereirwe et al., 2003, 2004). Many bacterial infections produce a cream or yellow-colored ooze that exudes within minutes of cutting the tissue, and large amounts can be produced over several hours. Colonies on the universal PDA medium would be yellowish (Figure 2). The disease symptoms on enset are slightly different from those on bananas and plantains. Greyish-brown spots cover the inner folds of the drooping heartleaf, and yellowish bacterial slime seeps from the vascular bundles when the leaf eventually emerges at the petiole (Figure 2) (Yirgou and Brandbury, 1968, 1974).

The entire enset plant dies when all leaves droop, bend over, and wither (Yirgou and Brandbury, 1968), but infected banana and plantain plants' male buds rot, the flower stalks turn yellow-brown, and the fruits ripen prematurely and unevenly, revealing internal browning; and pockets of pale yellow bacterial exudate appear after 5 to 15 minutes of cutting open the stems (Figure 3). On the contrary, farmers are not familiar with the disease symptoms, which are sometimes complicated by stress symptoms in plants (Gezahegn and Mekbib, 2016).

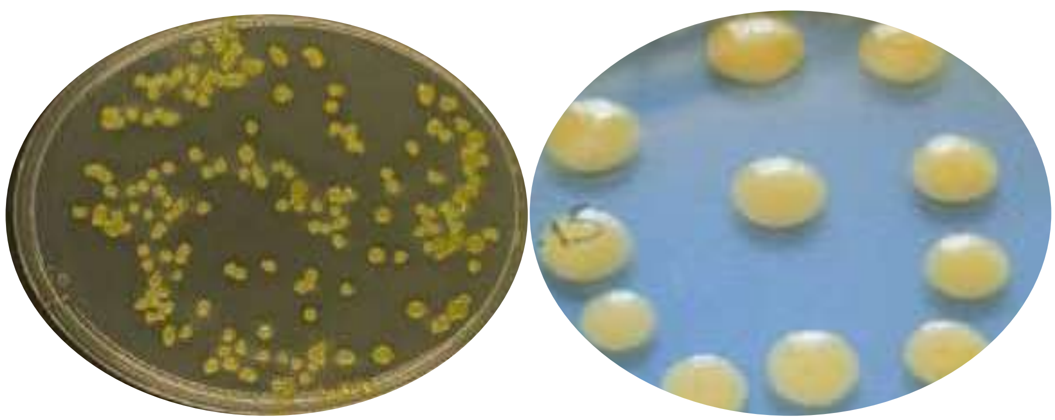

Figure 2. Typical yellowish colonies of *Xanthomonas campestris* pv. *musacearum* on yeast peptone glucose agar in Petri plates. Source: Ocimati et al. (2018).

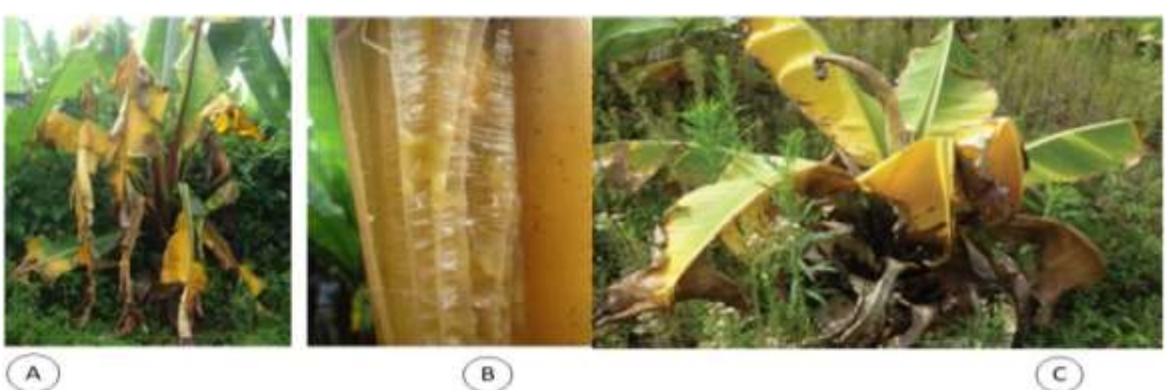

Figure 3. *Xanthomonas* bacterial wilt of enset caused by *X. campestris* pv. *musacearum*. The photos depict leaf yellowing and wilting (A and C), and pockets of bacterial ooze in a leaf petiole (B). Source: Guy Blomme et al. (2017) took photos in Ethiopia.

Epidemiological studies on enset bacterial wilt disease

Clone type, number of clones, population density in the field, and cropping practices could all influence the prevalence and severity due to Enset bacterial wilt (Mekuria et al., 2016). Enset bacterial wilt can affect any stage of plant growth. However, disease incidence varies with growth stage and disease intensity, becoming more aggressive at the age of four years on mid-age enset plants (Desalegn and Addis, 2015; Mekuria et al., 2016). After infection by enset bacterial wilt, the plant's tissues are known to be systemically invaded. Through inflorescence, the pathogen conducts a systematic upward and downward movement in vascular tissues (Tripathi et al., 2009).

Moisture is essential for the pathogen's survival in the soil. According to Welde-Mmichael et al. (2008), *Xanthomonas campestris* pv. *musacearum* (*Xcm*) can survive in the soil for up to 3 months in the absence of a host and up to 9 days in the soil, while petioles and leaf sheaths can survive for up to 3 months. The bacteria that failed to survive more than 90 days in moist soil and 30 days in dry soil (Mwebaze et al., 2006) and more than four months on host debris and residues were examined in laboratory and field conditions free of competition with other microorganisms in sterile soils (Welde-Michael et al., 2008; Tripathi et al., 2009). The disease stays up to 3 to 4 days on contaminated blades (Ashagari, 1985). According to the report of Fikre (2017), the pathogen was recovered from the fermented enset plant 105 days after fermentation. The disease is more severe in the highlands than in the lowlands, indicating that enset bacterial wilt prefers a humid environment and low temperatures for maximum damage rather than low humid and high-temperate areas (Mekuria et al., 2016; Ambachew et al., 2018). Furthermore, seasonal comparisons revealed that the disease was more severe in the summer than it was in the winter.

According to an analysis of the infection map of East Africa (Ocimati et al., 2019), Ethiopia was categorized as a hotspot and vulnerable landscape to the pathogen due to high precipitation and the presence of pathogen inoculum, as the occurrence of the disease increased with precipitation increase and poor sanitary and management practices.

Taxonomy of the pathogen *Xanthomonas campestris* pv. *musacearum* (*Xcm*)

Domain: Bacteria
Phylum: Proteobacteria
Class: Gammaproteobacteria
Order: Xanthomonadales
Family: Xanthomonadaceae
Genus: *Xanthomonas*
Species: *Campestris* pv. *musacearum*

However, fatty acid methyl ester studies as well as genetic and genomic evidence indicated that this pathogen is *Xanthomonas vasicola*, and it has been classified as a species of *Xanthomonas vasicola* (Nakato et al., 2018; Studholme et al., 2019).

Sources of inoculum, mode of infection and transmission

With reference to the seriousness of the disease, the sources of inoculum, mechanism of infection, and transmission of *Xanthomonas campestris* p.v. *musacearum* (*Xcm*) particularly in Ethiopia of enset, have not yet been properly studied. However, a few research have revealed certain information about inoculum sources, mechanism of infection, transmission, and *Xcm* survival. *Xanthomonas campestris* p.v. *musacearum* (*Xcm*) can persist in the soil for a certain period (Quimio and Tesera, 1996; Mwebaze et al., 2006; Welde-Michael et al., 2008). The bacteria can survive in chopped plant debris in the soil for more than six months. Plant residues, contaminated soil and water (water flowing from infected to uninfected fields), infected mats, and trade goods, such as fruits, leaves, and planting materials (suckers and corms) are the main sources of inoculum (Million et al., 2003; Eden-Green, 2004; Mikias et al., 2011). Another investigation shows that *Xcm* could persist on the surface of contaminated knives for up to four days (Ashagari, 1985) and could transmit the disease from infected to healthy plants (Ashagari, 1985; Welde-Michael et al., 2008).

Transmission of enset bacterial wilt from diseased to healthy crop plants can take place through a number of routes, although infected farm implements are the most common inoculants (Dereje, 1985; Million et al., 2003; Karamura et al., 2006; Welde-Michael et al., 2008; Mikias et al., 2011). Animals grazing on diseased leaves, the use of infected plant materials, frequent transplanting, which damages corms and roots, and possibly insects visiting bacterial oozes on enset foliage are all possible ways for the disease to spread (Yirgou and Bradbury, 1974; Eshetu, 1981; Yesuf and Hunduma, 2012). Although insect vector transmission of *Xcm* in enset has been reported (Eshetu, 1981; Fikre et al., 2012), there is no clear information on insect and soil-borne pathogen-mediated transmission of *Xcm* in enset.

In general and according to reports of Brandt et al. (1997), anything that was exposed to infected plant parts can quickly spread the pathogen. Cannaceae (*Cana* family), Costaceae (*Costus* family), Heliconiaceae (*Heliconia* family), Marantaceae (prayer plant family), Strelitziaceae (birds of paradise flower family), and

Zingiberaceae (ginger family) are regarded to be host plants to *Xanthomonas campestris* pv. *musacearum* (cause of enset bacterial wilt) (Karamura et al., 2008). According to the findings, the pathogen's transmission method appears to be mediated by a number of factors (Figure 4). A study on *Xcm* transmission by insects on enset indicates that insect vectors (Eshetu, 1981) could transmit the pathogen. In the same way, farmers claim that an insect vector (Tariku, personal communication) spreads the infection. This fact, however, is not yet truly recognized. The role of insect vectors in the ABB genotype of bananas through male buds has been highlighted by the fact that early de-budding effectively stops disease spread (Karamura et al., 2008).

Contaminated instruments used in ordinary field activities (pruning, de-leafing, digging, weeding, and harvesting) constitute a primary mechanism for disease spread both locally and between farms (Million et al., 2003; Karamura et al., 2006; Mikias et al., 2011). The disease is believed to be spread by vertebrate pests, such as mole rats and porcupines (Shank and Cherenet, 1996; Brandt et al., 1997; Mikias et al., 2011). The disease is also predicted to spread among domestic animals, such as cattle (Mikias et al., 2011). Although there is evidence that bats and birds can transmit the disease in the case of bananas (Karamura et al., 2008), there is none in the case of enset *Xcm*. These organisms must be considered and their role as disease vectors cannot be ignored. The entrance of the pathogen into bananas is enhanced by mechanical injury or injury caused by soil-borne organisms, such as nematodes and insects, as shown in the study. In the case of enset, however, additional investigation is warranted.

The bacterium is spread by everything that gets in contact with an infected banana or enset, such as insects and birds, sucking nectars or feeding on ripened fruits, grazing animals, cutting tools, and unintentional moving of infected soil on boots, symptomless infected suckers, or marketed infected bananas/ensets (Figure 5).

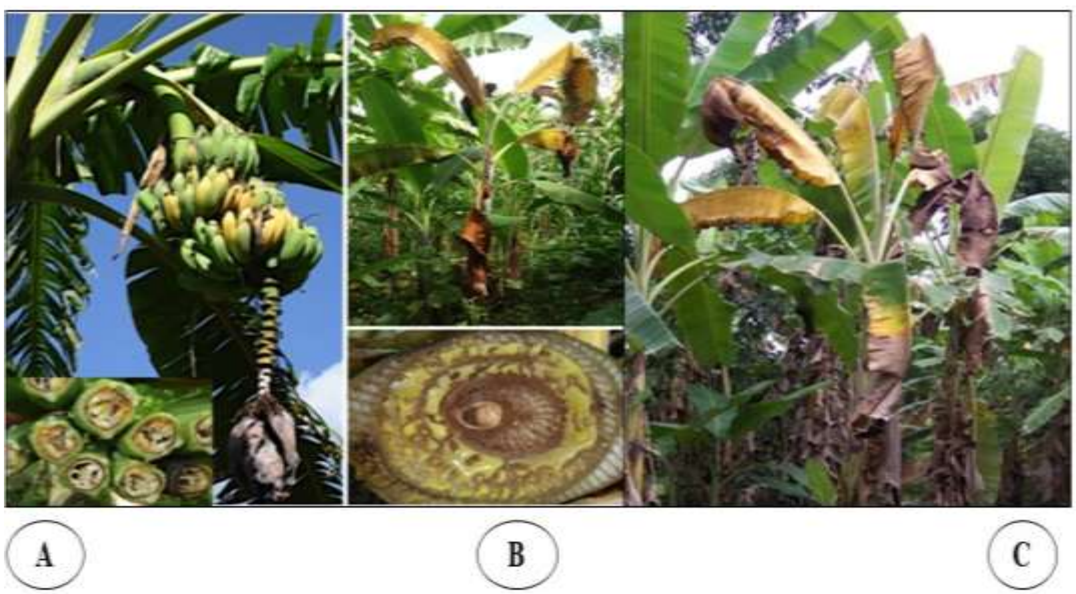

Figure 4. *Xanthomonas* bacterial wilt of banana caused by *X. campestris* pv. *musacearum*. Premature fruit ripening and fruit discoloration (A); Exudation of bacterial ooze (B) and photos depict leaf yellowing and wilting (C). Source: Photos were taken.in Uganda by Guy Blomme et al. (2017).

Management challenges of enset bacterial wilt

According to Ambachew (2019) who authored a recent review on the impact of banana bacterial wilt, differential reactions of cultivars have been observed to the disease in the field. According to the same authors, the identification of resistant genotypes or clones and the development of resistant cultivars through conventional breeding are the major challenges, because little information is known about the caudal bacterium *Xanthomonas campestris* pv. *musacearum* life cycle. It is important to look at the mechanisms that cause the host plants to react differently. The wilt research agenda requires a good understanding of the pathogen's life cycle and its importance in epidemic development in bananas and enset. Pathogen population structure, diversity, and phylogeny information are still lacking, but they are crucial in establishing the best strategy for

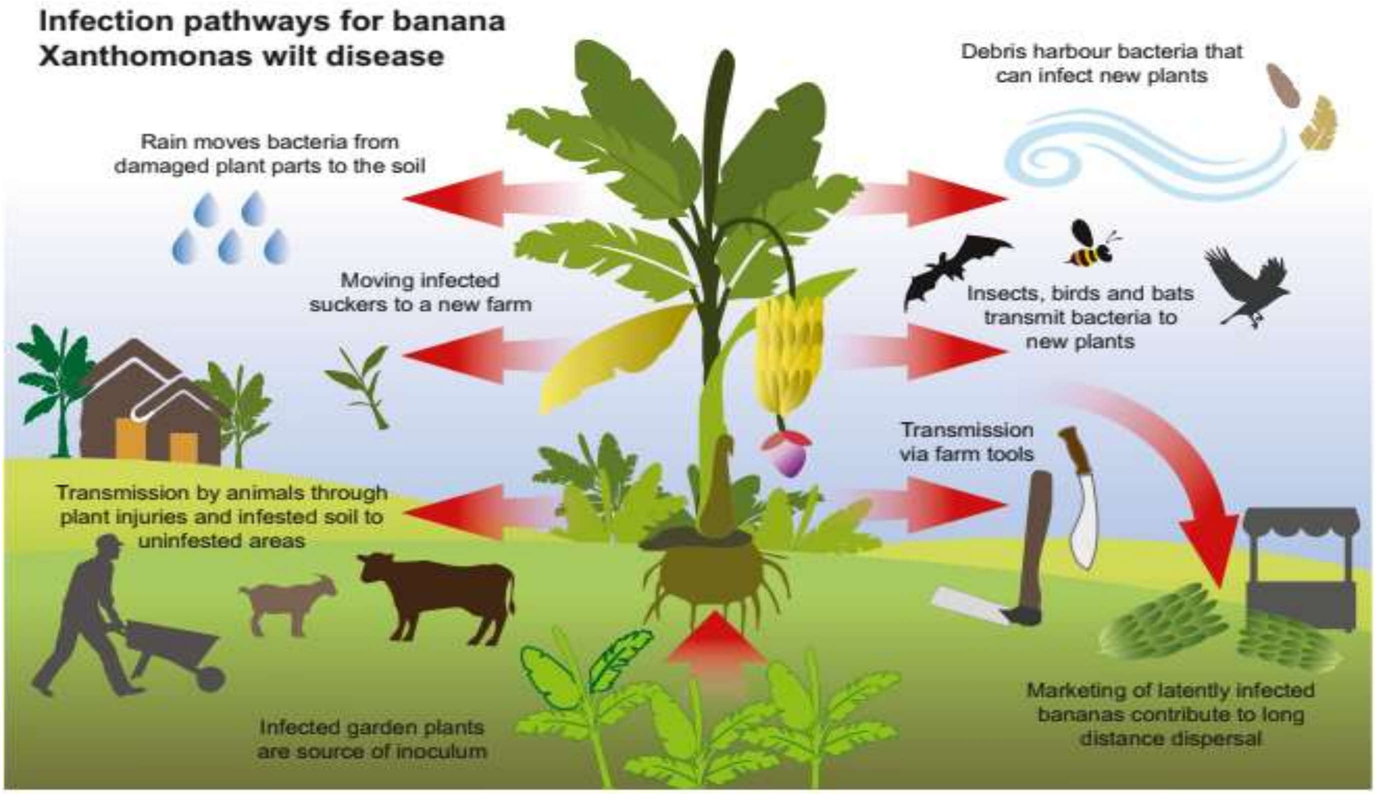

Figure 5. Transmission of the bacterium *Xanthomonas campestris* pv. *musacearum* causing banana/enset wilt. Source: Uwamahoro et al. (2019).

resistance deployment. The duration of bacteria survival in the soil is unknown, and determining the relative importance of different infection routes remains a serious difficulty (Brandt et al., 1997).

MANAGEMENT OF ENSET BACTERIAL WILT

Overview

Managing bacterial wilt disease of enset is difficult in general. The development of efficient management strategies has been limited by the lack of adequate information on the pathogen's biology and epidemiology as well as the perennial nature of the plant. As a result, management strategies have emphasized reducing the pathogen's initial inoculum and subsequent transmission. Awareness creation and community mobilization for eradication of infected plants; appropriate cultural practices and sanitary management measures; use of resistant or tolerant enset clones; use of healthy and clean planting materials (suckers and corms); and integrated disease management are widely realized effectively as *Xanthomonas campestris* pv. *musacearum* management strategies.

Cultural practices

The pathogen's spread was significantly reduced because of cultural practices and sanitary measures (Million et al., 2003; Karamura et al., 2008). Uprooting and burying/burning infected enset plants (eradication/roguing and disposal of diseased enset plants and debris from the fields) have also resulted in good management options, as diseased enset plants and debris are potential sources of primary inoculum. According to Karamur et al. (2005), early detection and eradication of infected plants is a vital step in preventing disease spread.

According to Million et al. (2003), 71% of farmers said that meticulous application of sanitary management measures may assist in the suppression of enset bacterial wilt disease. To prevent disease spread, the same authors also suggested the use of cultural techniques, such as deep tillage; exposing the soil during the dry season before planting, correct spacing, and spot rotation of affected locations. Warding off porcupines, mole rats, and other domestic animals that may transmit the pathogen within the fields and surrounding areas as well as preventing overflow of water from infested to uninfected fields would help to reduce pathogen spread

(Shank and Cherenet, 1996; Brandt et al., 1997; Mikias et al., 2011).

For the management of enset bacterial disease, the use of clean planting materials (suckers/transplants, corms) and stringent controls on the movement of planting materials from one area to another, i.e. establishing a local quarantine system, are also strongly recommended (Brandt et al., 1997), thereby contributing to the reduction of pathogen dissemination. In addition to the mentioned above, cultural and sanitary measures, uprooting the diseased enset plants and burying them in holes, clean and flaming equipment that has come into contact with infected plants are also best management approaches (Tariku et al., 2015; Mekuria et al., 2016; Ocimati et al., 2019). Reducing enset cutting frequencies when the disease is suspected; keeping fields and surrounding areas free of weeds and volunteer plants; exposing the soil before planting during the dry season; sanitary waste disposal is essential for preventing bacterial wilt disease and helps to prevent, reduce, or eliminate the disease's spread in the field as suggested by the same authors.

Regular field inspections and successful inoculum removal would greatly reduce infection levels. Disinfecting farm and processing instruments with sodium hypochlorite, NaOCl (bleaching agent or *berekina),* or fire (Karamura et al., 2008) has been shown to minimize disease transfer from infected to healthy plants. The campaign against *Xcm* wilt must be multi-faceted, requiring the mobilization of all human and financial resources available. Everyone must be aware of the details of the disease and be dedicated to managing it. All stakeholders have to get clear, concise, and appropriate messages outlining what needs to be done by whom, when, and where so that they can properly execute their responsibilities. Community mobilization and disease awareness creation as *Xcm* management experiences in enset and banana are vital in successfully managing the disease (Million et al., 2003; Tesfahun and Karamura, 2012; Yesuf and Hunduma, 2012).

Sensitization and mobilization of communities in various areas led to a significant decrease in the incidence of the enset bacterial wilt on the crop (Yemataw et al., 2016) and routine application of phytosanitary measures and agronomic practices to reduce disease spread at the individual and community levels is currently the most effective way of managing the disease caused by *Xcm*. It is unambiguous that concerted efforts were made to adjust the research strategy with adequate human and financial resources to effectively address the pathogen and clear messages to the scientific and local communities (Karamur et al., 2008) (Figure 6).

Figure 6. Cultural practices for the management of enset *Xanthomonas campestris* pv. *musacearum* (*Xcm*): A) Destruction and disposal of infected enset parts; B) Partial rotated enset fields, and C) Discussions andaction plan meetings at farmers' association and district levels to create awareness for the management of Xcm. Source: Fikre Handoro (2017) took photo in Ethiopia.

Host plant resistance

The use of resistant or tolerant host plants is another approach for bacterial wilt management. Farmers plant several enset clones in different enset-growing locations of the country, claiming that the clones exhibit varying degrees of susceptibility to bacterial wilt. Despite this, screening/breeding activities for tolerant/resistant clones' identification of the disease on this plant are limited due to the perennial nature of the plant when compared to resistance breeding on cereal crops.

Through some investigation and identification activities of tolerant enset clones, significant attempts have been made to mitigate the damage caused by enset bacterial wilt (Welde-Michael et al., 2008; Mengistu et al., 2014; Fikre and Alemar, 2016). Agricultural Research Centers in Hawassa and Areka, on the other hand, have been working hard in this area. In this connection, over 600 different enset vernaculars (clones) have been collected from different enset-producing areas and secured at the Areka and Hawassa Agricultural Research Center (Anonymous, 2001).

Screenings conducted at the Areka Agricultural Research Center using artificial inoculation and in different farmers' fields under natural disease conditions revealed that "Maziya" enset clone has better resistance/ tolerance than the clone "Arkia" (Table 2), which is highly susceptible to EBW (Fikre and Gezachew, 2007). Of course, developing tolerant/resistant enset clones requires more research into the genetic variation of the plant in the country as well as government support needs in connection to human resource development and finance allocation.

Table 2. Responses of certain enset clones to bacterial wilt investigation done through artificial inoculation of clones with *Xanthomonas campestris* pv. *musacearum* by different researchers at Areka Agricultural Research Center in Ethiopia over a decade.

Clones	Reaction to *Xcm*	Author
Warke bidu, Awenyi, Kekar	Susceptible	(Tariku et al., 2015)
Meziya, Hineba, Bedadet and Warke Dima	Relative tolerant	
Lemat, Nechuwe, Unjeme, Tikurenset, Nobo, He'lla, Dirbo, Wachiso, Hae'la, Falakia, Gefetano, Godere, Amiya, Yesha, Alagna Sirariya and Gisiro	Relative tolerant	(Fikre and Alemar, 2016)
Astara, Buffare, Geziwet2, Gulumo, Kullo, Ado, and Genticha	Susceptible	(Welde-Michael et al., 2008)
Buacho,Wonigoro, Bazeriet, Dere	Moderate tolerant	
Anikefye, Eminiye, Lemat and Nechwe	Relative tolerant	
Gimbwe, Terye, Agade, Yeshrakinke, Kechere, Badedat and Ferezye	Moderate Resistant	(Mekuria et al., 2016)
Kibinar, Yegendeye, Astara and Ewane.	Susceptible	

Sources: Welde-Michael et al., (2008), Tariku et al. (2015); Fikre and Alemar, (2016), Mekuria et al. (2016).

Biological Control

Biological agents, such as antibiotics, lytic enzymes, and hydrogen cyanide (HCN), compete for nutrients and space to manage plant diseases. They can considerably improve plant health and promote growth, vigor, and yield by doing so. Abayneh (2010) discovered *in vitro* test using a dual culture experiment that seventeen fungal isolates and three bacterial isolates were active against *Xanthomonas campestris* pv. *musacearum*. Three bacterial antagonistic isolates (AUbB1, AUbB2, and AUbB3) from a genus of *Pseudomonas* were tested against enset *Xanthomonas* wilt and showed a reduction in disease severity that ranged from 56.4 to 74.8%, while one (AUFB 11) fungal antagonistic isolate, *Trichoderma* sp., showed a reduction in disease severity that ranged from 56.4 to 74.8% from potential candidates both under pot and greenhouse trials. Bacterial antagonistic isolates showed a significant reduction in disease when compared to the positive control, suggesting that bacterial wilt might be suppressed with bacterial antagonists. Some bacterial isolates, such as *Burkholderia*, *Herbaspirillum* and *Enterobacter* spp., isolated from banana tissues collected from different locations in Uganda, have shown promising levels of *Xcm* suppression in laboratory investigations on bananas (Mahuku, 2016).

Botanical control

Traditionally, farmers have been using medicinal plants, like *Olinia rochetiana* A. Juss, *Clematis simensis* Fresen, *Inula conferiflora* A. Rich, *Dodonaea angustifolia* L.F., and *Echinops kebericho* Mesfin to manage diseases using their indigenous knowledge (Daniel and Getaneh, 2015). Similarly, some innovative farmers have extracted the juice of those plants and applied them for bacterial wilt disease management. However, verification or validation of potential herbal bactericidal efficacy is required.

According to Daniel and Getaneh (2015) *in vitro* study, botanical plant extracts in combination with *Etecha* and *Kabericho* extracts showed a significant suppressive effect with a 14.05 mm inhibition zone, followed by the standard check penicillin (with 21.02 mm inhibition zone), which is strongly antibacterial action against *Xanthomonas campestris* pv. *musacearum*. However, the efficacy of using those plant extracts alone to inhibit infection significantly decreased. The same authors demonstrated in their research work that a single *Etecha* plant extract and a combination of three, i.e., *Solle*, *Hidafite*, and *Tembos* plant extracts, resulted in 11.78 and 12.08 mm inhibitory zones, respectively, indicating a promising efficacy against bacterial isolates. Farmers in the Kembata-Tembaro zone of southern Ethiopia also cultivate '*Tonsowo*' plant (local plant name) as a botanical to manage enset bacterial wilt in enset crops (Tewodros and Tesfaye, 2014).

Antibacterial compounds in extracts from *Agarista salicifolia*, *Pycnostachys abyssinica*, *Achyranthes aspera, Datura stramonium*, *Melia azadirachta,* and *Vernonia amygdalina* were evaluated *in vitro* for the presence of antibacterial compounds and the extent of inhibition against bacterial wilt (Getahun and Fetene, 2017). These authors found that there are variations in the type and amount of chemical categories in the plant extracts as well as the availability of the metabolites.

The concentration of alkaloids, flavonoids, phenols, saponins, tannins, and terpenoids in methanolic extracts of *A. salicifolia* and *P. abyssinica* may explain their strong antibacterial activity. *Agarista salicifolia* extract also includes glycosides (Getahun and Fetene, 2017). The same authors reported that *A. salicifolia* and *P. abyssinica* had a high efficacy on the pathogen, probably due to their high phenolic contents. Extracts of *Eucalyptus, citriodora* and *Ricinus. communis* had higher potency activity against the disease at 50 and 100 mg ml^{-1} test concentrations, whereas *Bersama abyssinica* had stronger efficacy at 200 mg ml^{-1} concentration than those extracts effective at 50 and 100 mg ml^{-1}, implying that different botanicals have significant efficacy differences at different concentrations (Getahun et al., 2019).

According to Getahun and Fetene (2020), treating enset clones with crude leaf extract of *Agarista salicifolia* can improve crop production and reduce disease incidence in a non-genetic approach. Induction promotes the physiological processes of healthy plants in addition to inducing resistance in the plant. Resistance induction reduced disease incidence in susceptible individuals by 33.5%, indicating that resistance induction can be used to manage enset bacterial wilt as an alternative.

Integrated disease management (IDM)

Using appropriate management practices, one alone and a combination of sanitary management measures, improved cultural practices, disease-free and resistance/tolerant enset clones was implemented in an integrated manner through subsequent awareness creation, and training of stakeholders and was found to significantly reduce enset bacterial wilt disease incidence by 21 to 89% (Fikre, 2017).

To limit the transmission of disease in the field and reduce damage by the disease, around 71% of farmers utilized meticulous application of sanitary management techniques, such as removing infected plants and burying them, restricting animals from roaming around and browsing, burning working instruments, using disease-free suckers, and crop rotations (Tariku et al., 2015). To manage the disease, it is also critical to create awareness and mobilize the community. Farmers in different zones are most familiar with the use of sanitation and cultural practices, but they do not put them into practice adequately due to a significant need for chemical control measures from concerned bodies and the assumption that Integrated Disease Management without chemicals is labor-intensive and time-consuming (Fikre, 2017). Sanitary measures, cultural practices, and the use of resistant/tolerant clones have to be integrated to reduce the damage by enset bacterial wilt (Tariku et al., 2015; Yemataw et al., 2016).

Integrated disease management can reduce the disease severity by 10 to 54.5% by combining the tolerant Maziya cultivar with intensive sanitary measures and cultural practices (Yemataw et al., 2016). So far, no chemical trials have been conducted, and no information on the use of chemicals as a management option for enset bacterial wilt has now been in practice. Although microbial antagonists were shown to be effective in the biological control of bacterial diseases (Priou et al., 2005), this strategy is at an infant stage and has yet to be used in the management of *Xanthomonas campestris* pv. *musacearum*. A persistent and continuous public awareness creation program about enset bacterial wilt disease is required in addition to what has been tried to manage the disease and sustain enset production and productivity in Ethiopia.

CONCLUSION

Enset is one of the root crops, used as staple food for many Ethiopian peoples. Despite its largest production status in the southern and western parts of the country, the production and productivity of enset are challenged by different biotic and abiotic factors. Enset bacterial wilt is the most important and destructive disease, mainly influencing enset production in Ethiopia and bananas in East African countries. Enset and banana bacterial wilt, which is caused by *Xanthomonas campestris* pv. *musacearum*, is one of the major diseases in the enset-growing zones in the country. In this piece of work, attempts have been made to review the economic importance of bacterial wilt, the biology of the pathogen, ecological requirements for epidemics, and management options for sustainable enset production and productivity. Enset bacterial wilt could cause yield losses of up to 100% on susceptible varieties/clones in favorable and severe conditions worldwide, leading to epidemic status.

Modernizing farming methods is required and a good alternative for managing crop diseases. There is no single satisfactory method to manage enset and banana biological wilt with perspective grower locations. Even if the studies on management options were limited, management measures, such as cultural, host resistance, biological, botanicals, and community participation and awareness creation basis and integration of multiple management approaches are needed. A national strategy on the management of the disease should be developed to limit the further widespread of bacterial wilt across the entire enset-growing areas of the country, particularly on awareness creation focusing on community-based sanitary measures and development of resistant/tolerat varieties through relevant resistance gene development.

There is a limitation of information on resistance breeding for genetic improvement to overcome the disease, except for some conventional breeding for selection. Botanicals and indigenous bio agents should be studied more than the current state since there are limited pieces of research information in this direction. The benefit of transgenic approaches demonstrated for banana against bacterial wilt should be considered and adopted for enset resistance improvement.

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