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REVIEW ARTICLE

Bacterial diseases seriously infecting major horticultural crops in Ethiopia and their management

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ABSTRACT

Horticultural crops that can solve food insecurity problems are essential commodities. The availability of diverse soil, favorable climatic conditions, and comfortable agro-ecological zones in Ethiopia provide ample opportunities to produce them. However, the success of production has been challenged by biotic and biotic factors. From which, diseases caused by bacterial pathogens are the current globally emerging and re-emerging threats of crop production. Hence, this review is crucial to accentuating newly emerged and re-emerged bacterial diseases that cause great economic damage to essential horticultural crops in the country. Many African countries are experiencing outbreaks and the potential for these bacterial pathogens to emerge. Among these, many hosts killing and yield loss problems due to ginger bacterial wilt (*Ralstonia solanacearum)*, bacterial blight of coffee (*Pseudomonas syringae)*, banana, and enset wilt (*Xanthomonas campestris)* diseases result in > 50% yield reduction. Various factors like introducing new types within a species, homogeneity of resistant plant varieties, hybridization within pathogen species, and introducing an arthropod vector to be "emergence" or increase in importance within that environment to favor their distribution. Once they are established, bacterial disease management is so complex both by chemical and biological means. In all, this article is crucial to offer detailed insight on some bacterial diseases that threaten the production of economically essential horticultural crops.

INTRODUCTION

Agriculture is the foundation of the Ethiopian economy with a contribution of 43% to GDP, 83.9% to total export and 80% to employment in the country and 75% of the industries present in the country are engaged in processing farm products (Duressa, 2017). It providing employment, and maintaining the country's ecological balance (Bezabih et al., 2014; Ashinie and Tefera, 2019). However, the yield potential of these crops is very low owing to lack of usage of improved agricultural technologies, reduction in the landholding, weather conditions, diseases, and pests (Azerefegne et al., 2009; Ashinie and Tefera, 2019). Currently, emerging and re-emerging have a serious effect on crop productivity in East African countries, including Ethiopia (Malhotra, 2017; Duressa, 2018), and cause an average of 20 and 40% yield losses in these countries (Savary et al., 2012).

Fruits and vegetables are affected by various fungal, bacterial, and viral diseases (Mohammed et al., 2006). They differ in terms of habitat, phylogeny, effects on hosts, and environmental health (Sundin et al., 2016; Gwyn and Beattie, 2006). The most common bacterial diseases occurring on different crops are bacterial wilt (*Ralstonia solanacearum)*, Xanthomonas wilt (*Xanthomonas campestris),* etc and these diseases are reported to cause 50% yield reduction in fruits and vegetables (Janse, 2012). These bacterial diseases are major threats to essential horticultural crops, especially ginger, coffee, banana, Enset, etc., in Ethiopia. Because of these factors, this review aims to address the risk posed by major bacterial diseases and to offer insight on risk lessening alternatives in the country.

GENERAL OVERVIEWS OF PLANT PATHOGENIC BACTERIA (PPB)

Major emerging and re-emerging bacterial diseases

When a disease is caused by newly emerged microbes that were not previously known to infect crops, it is referred to as emerging diseases, whereas the occurrence of outbreaks of previously declined infectious diseases globally or in specific countries is referred to as re-emerging diseases (Vurro et al., 2010). Furthermore, an emerging disease is a one-of a-kind case that has recently flourished in an area with a rapid increase in incidence and severity and can cause crop disaster epidemics. These diseases are today's serious challenge for several crop production in Ethiopia. Here, the most economically important emerged and newly emerging bacterial diseases are listed below. Why do I want to limit myself to bacterial blight of coffee and wilt diseases of ginger, banana, and enset? Because these are the current alarming diseases causing significant economic loss on these essential crops used as economic pillars, particularly for communities and the country as a whole.

BACTERIAL BLIGHT OF COFFEE (BBC)

Coffee (*Coffea arabica* L.) is the most essential crop that acts as an engine for the Ethiopian economy (Chauhan et al., 2015) and contributes more than 27% of foreign exchange earnings and more than 25% of rural and urban employment for the community (Zenebe and Dawit, 2020). However, its production has declined due to different factors, such as the BBC.

Bacterial blight of coffee is the major bacterial disease that causes severe damage in different crop stages, especially in the wet seasons worldwide (Amaral et al., 1956; Eshetu et al., 2009). It was previously known as "Elgon dieback" and "Solai dieback" derived from the areas where the disease occurred (Kairu et al., 1985; Gichimu et al., 2013). After its occurrence, the disease has a high progression that makes its control difficult at nursery and plantations. Moreover, plant density favors disease development and contributes to direct contact between leaves of susceptible host plants associated with the excess moist environment for pathogen spread and epidemic occurrence. Hence, occurrence, distribution pattern, and epidemics progress depend on initial inoculum origin (Brasil, 2009).

Disease cycle and Disease symptoms

The main inoculum reservoirs for pathogen inoculums sources for disease epidemics are latent infection, epiphytic populations, overwintering sites on infected hosts, orchard ground covers, weeds, and detached liters (**Figure 1**). During the winter season, it becomes dormant in infected tissue, and healthy tissue infection can occur whenever the bark of trees becomes warm due to sunshine from the southwest side of the trees (Korobko and Wondimagegn, 1997; Hislop, 1976; Maghuly et al., 2020).

The inherent growth and flowering of *C. arabica* trees are governed by the annual rainfall pattern and are greatly influenced by the BBC's seasonal periodicity (Ramos and Kamid, 1981). Phytopathogenic bacteria can't be able to make their entry ports in the plant tissue; instead, they need natural openings factors as the main actors for entry (Hellmann et al., 1997; Agrios, 2005).

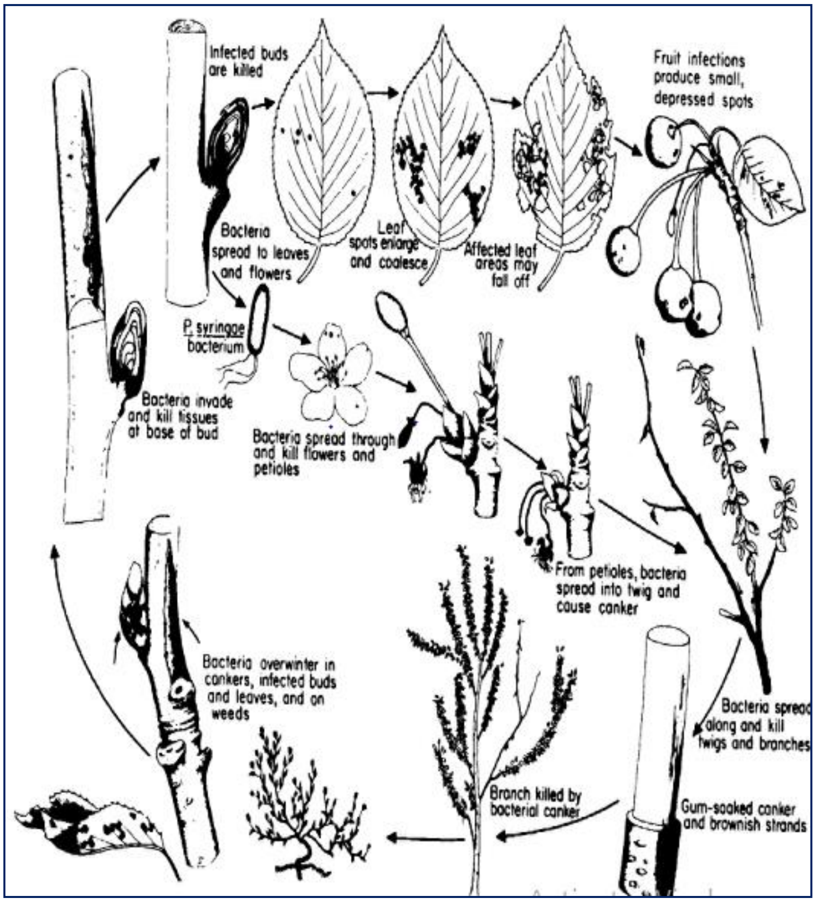


Figure 1. The general life cycle of *Pseudomonas syringae.* Adapted by Webster (1970)

The observable symptoms on leaves at the nursery and fields are similar (Pozza et al., 2010; Rodriguez et al., 2013). Belan et al., 2016). When the terminal bud shoots infected, the infection moves down, causing dieback, and axial buds on young branches from the tip are vulnerable to infection (Mugiira et al., 2011). Lesions can griddle the branch and damage the vascular tissue (**Figure 2**) and be a severe problem at high altitude; having a biomodal rainfall pattern and often experiencing storms accompanied by hail (Groenen, 2018).

Figure 2. Common and noticeable symptoms of Bacterial Blight of coffee

Distribution and economic importance

BBC was a serious concern in Kenya in 1983 (Mugiira et al., 2011). Since then, it has become a major concern, with cases being recorded in Brazil, Uganda, and China (Silva et al., 2006). In Kenya, 30 percent yield loss has been recorded, posing a serious problem in high-altitude areas characterized by strong winds, prolonged bimodal pattern rainfall, and storms with hail (Janse, 2010). Also, it is assumed to encourage berry rot, and beans are darkening in association with the infestation of Antestia bug (Antestiopsis spp.) mainly at lower altitudes (Eshetu et al., 2000). In Ethiopia, the disease was first reported by Korobko and Wondimageng (1997) from Sidam Zone and was detected as an unknown disease with blight syndrome widely on coffee trees. After six detailed survey works and investigations undertook, the disease causal pathogen, nature, determinant causes, occurrence, and distribution with other weather factors were elucidated (Girmaet al., 2008) and observed in 2 woredas (Sidama and Y/chefe) of southern Ethiopia (Girma et al., 2014). The BBC has recently dispersed throughout the country's coffee-growing regions (**Figure 3**). After that, 70-80% field infestation was recorded from the Sidama zone while disease incidence and severity vary with altitude range (**Figure 3**) adapted by Belan et al. (2016).

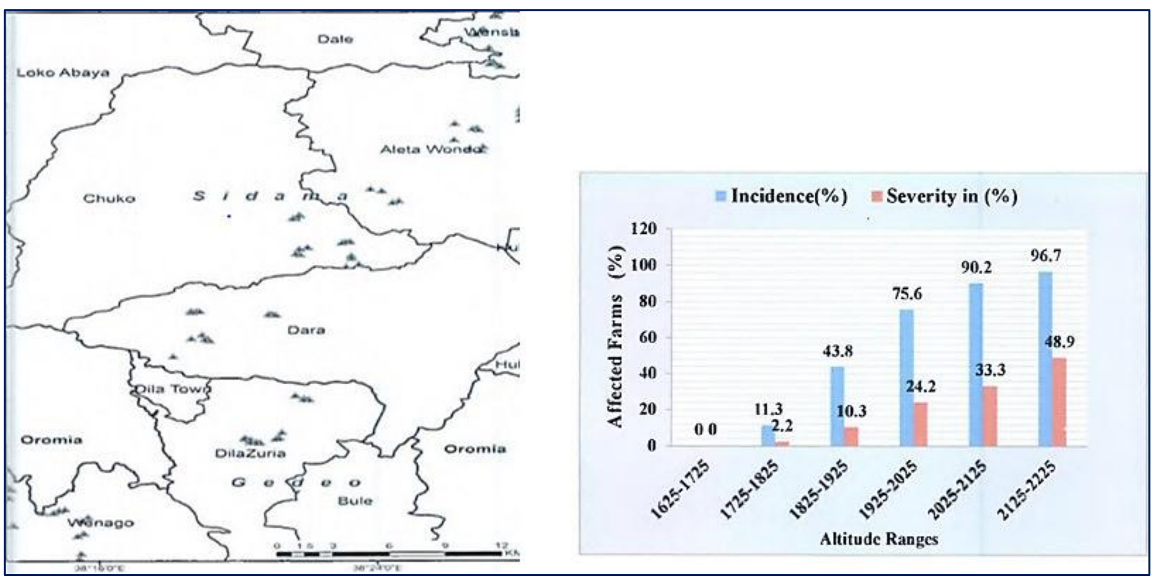


Figure 3. Disease distribution map (left) and Intensity (right) of coffee bacterial blight in altitude ranges (Hinkosa et al., 2017)

Management options

Starting from 5 years ago, BBC has re-emerged as a serious problem in Ethiopia. Because there is no single recommendation for BBC management, researchers and farmers in the field are currently using the following options to manage the major coffee diseases, including this disease.

Cultural practices

Pruning: is an essential part of coffee production, primarily for branch thinning and the removal of old dead stems, determining tree shapes, maximizing the amount of new wood for the following season's crop, preventing over-bearing and reducing biennially, and assisting in the prevention of disease problems (Hinkosa et al., 2017). Bedimo et al*.* (2007) noticed that pruning during the vegetative growth period is used as a means of removing diseased branches, leaves, berries, susceptible and old trees and reducing the initial inoculum. For example, in the study by Probst et al. (2016), disease incidence was reduced from 46% to 10% as a result of pruning.

Mulching and cover cropping:

Mulching involves covering the soil with a layer of dry vegetation. The most commonly used mulching and cover cropping materials in Ethiopia are vetiver grass, common beans, maize stover, banana leaves, and coffee prunings, which are used to reduce soil moisture loss, prevent soil erosion, increase soil nutrient levels, improve soil structure, and suppress weeds. Soil nutrient management and shading coffee trees are the major practices that affect bacterial blight of coffee (JARC unpublished).

Use of resistance varieties:

BBC resistance varieties aren't developed in Ethiopia. Rather, producers use varieties developed for other major diseases (**Figure 4**) like coffee leaf rust and coffee berry diseases, etc. (Silva et al., 2006; Avelino et al., 2011; Teferi and Ayano, 2017).

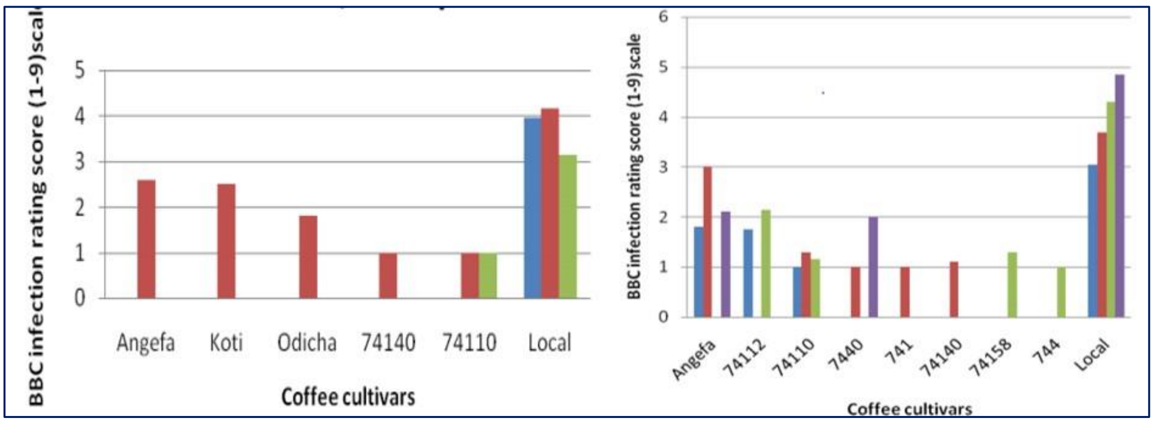


Figure 4. The response of released coffee varieties for bacterial blight of coffee at Sidama and Gedio Zones respectively (Teferi and Ayano, 2018)

Chemical control

Different copper compounds with or without combinations of fungicides and, to a lesser extent, including antibiotics can be used (Belan et al., 2018). Copper fungicides are intensively applied to reduce heavy crop loss or eliminate damage to coffee trees and harvest good yield (Kairu, 1999). Foliar feed application encourages growth conditions of BBC development and reduces the efficacy of copper sprays against the disease (**Table 1)**, Hinkosa et al., (2017). Currently, new directions like using elicitors such as hairpins and polysaccharides like chitosan inhibit *PSG* in in-vitro conditions (Lamichhane et al., 2014). According to Monchiero et al. (2014) chemicals efficacy test experimental report, the combined application of 30mg (m/g/hl) of copper oxychloride and copper hydroxide (IRF 155) is more effective for controlling bacterial diseases caused by *Pseudomonas* spp. and can reduce 70-80% of disease symptoms.

Table 1. Fungicides used to control Bacterial blight of coffee

Common Names	Proprietary name	Formulation	Rate (kg ha^{-1})
50% Copper formulation	(i) Kocide 101	50% Cu W.P.	7.0
Cupric hydroxide	(ii) Parasol	50% Cu W.P	7.0
	(iii) Champion	50% Cu W.P.	7.0
Cuprous oxide	(iV) Copper Sandbox	50% Cu W.P.	7.0

Copper oxychloride	Comox	50% Cu W.P.	7.0
Coppersulphate(CuSo4)-10kg +Lime (Cao)-10kg+water-1000 litters ha^{-1}	Bordeaux mixture	25% Cu W.P.	10.0
Copper +antibiotic	kasugamycin kasumin Bordeaux	45% +5% W.P.	4.0

Source: Hinkosa et al. (2017)

GINGER BACTERIAL WILT (GBW)

In Ethiopia, ginger is one of the most important crops for small-scale farmers. Its cultivation is concentrated in the country's southern regions, accounting for about 35% of total output (Bekle et al., 2016). It has been used as a human medicine since ancient times. Its production, however, has been limited due to a variety of biotic and abiotic factors. Among these, *Ralstonia solanacearum* is the current cause of ginger bacterial wilt.

The pathogen's life cycle and epidemiology

Ralstonia solanacearum (*RS*), a member of the Proteobacteria subdivision, Ralstonia group, and genus Ralstonia, (Yabuuchi et al., 1995). The bacterium that inhibits plant and soil growth reaches the roots through wounds (McCarter, 1991; Denny, 2006; Habetewold et al., 2015). After returning to the environment by destroying the host, it starts to survive in soil, water, or reservoir plants (**Figure 5**). High inoculums increase the expression of pathogenicity gene repressed by low bacterial densities in non-host environments (Álvarez et al., 2010).

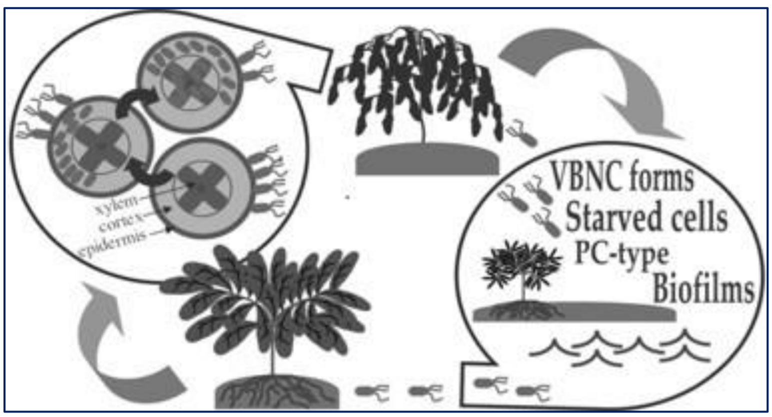


Figure 5. The life cycle of *Ralstonia solanacearum* inside and outside the host cells (Álvarez et al., 2010)

Distribution and economic importance

GBW was first reported from India in 1941 by Thom and then from Hawaii, Indonesia, and China in 1962, 1977, and 1994. It has now spread throughout the agroecology, causing high infectivity and economic losses (Hayward, 1991). Furthermore, yield losses of 50 and 100% due to rotting of rhizomes have been reported from Hawi and India, respectively (Yu et al., 2003; (Moslem et al., 2005).

In Ethiopia, GBW disease occurrence in ginger has recently been reported (since 2006) and is becoming a severe challenge to ginger root acreage and sales (Zenebe, 2018). Disease epidemics cause significant crop losses and discourage growers from farming edible ginger to shift their farms from infested locations to wilt-free ginger fields nomadically. It is challenging to obtain pathogen-free ginger seed, inhibiting new farmers because it has been transmitted via pathogen-contaminated shoes or tools to new areas. Also, bacterial wilt disease is rapid with severe crop losses and significant disease in ginger producing countries (**Table 2**; Tariku et al., 2016).

Table 2. Ginger bacterial wilt disease incidence in different countries

Country	Disease incidence in %age	References
Hawaii	50	1999 report, Yu et al. (2003)
India	38-100	Bholanatl et al. (2014)
Ethiopia	10-100	Ibrahim and Alemu (2017)
Dajeeling	80-84	Sharma et al. (2015)
Western india (Bengal)	95	Rai (2006)
China	20-50	Yang et al. (2015)
India	>50	Shara and Dutta, (2015)

Source: Zenebe (2018)

GBW symptoms

GBW causes symptoms like "Green wilt" which occurs early in the disease cycle precedes leaf yellowing, shoot browning, white milky bacterial streaming on the rhizome (**Figure 6**). *RS* blocks the water-conducting vascular system on the green ginger stem and leads to rolling and curling due to water stress on leaves; infected leaves turn to yellow and necrotic brown (Tariku et al., 2016). Fusarium yellows caused by *Fusarium oxysporum* on ginger can cause similar disease symptoms and confuse identification in the field. But, the clear difference is that it can't cause rapid wilting like ginger bacterial wilt. Instead, fusarium-infected ginger plants showed stunted and yellow symptoms (Sobiczewsk,2008; Bekele et al., 2016).

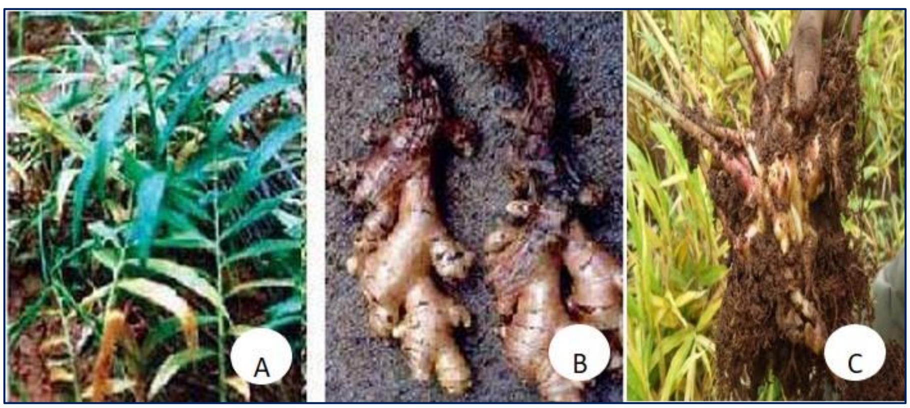


Figure 6. Ginger bacterial wilt symptoms. Infected leaves (A), rhizomes (B), &underground infection (C) (Source: edited figure from https://vikaspedia.in/agriculture/crop-production/integrated-pest-managment)

Current Status and distribution in Ethiopia

The disease is newly emerging, threatening ginger production, and its epidemics have been distributed across ginger-producing areas of the country. The pathogen is a lethal pathogen that causes vascular disease in Solanaceae crops such as potato, ginger, pepper, tomato, and eggplant, all of which are economically important. While the host ranges of *R. solanacearum* race 4 is restricted to edible ginger (Duressa, 2018). GBW disease was first reported from the Benchmaji zone of Southern Ethiopia and distributed to the nearby areas of Wolayta and Sheka zones with 22.3 and 67% yield loss, respectively (Bekelle et al., 2016). Yield loss can vary across agro-ecologies, weather conditions, climate, soil type, cropping pattern, and pathogen strains. A severe outbreak of GBW was reported by agricultural bureau experts mainly from Southern Nations, Nationalities, and People during 2011/12, 2012/13, and 2013/14 consecutive cropping years. From 1530 hectares of ginger plantation assessed, 80-100% bacterial wilt incidence was recorded at the end of June to mid-July/in the primary rainy season and warm, humid weather conditions. Environmental change favors a rise in incidence, severity, and disease distribution across ginger-producing areas (Bekele et al., 2016; Jibat and Alo, 2020).

Management practices

Cultural practices

Plant pathogen-free seed:

Planting pathogen-free seed; dipping in 10% (1 part bleach and 9 water) solution used to produce bacterial wilt-free ginger via sterilizing ginger seeds surface in the greenhouse (Kumar and Hayward, 2016).

Hilling, cultivation, and drainage:

Hill is the essential method allowing row planting to promote roots aeration and adequate soil drainage. Ensure adequate soil drainage, hilling must be done within 6-weeks interval (Nion and Toyota, 2015).

Limit site traffic and pathogen dispersal:

Because the pathogen can be found in soils, truck tires, or shoots, restrict non-farm vehicles and visitors' movement to facilitate dispersal, disinfect infected farm tools, and discourage cattle and other animals from entering via fencing (Kurabachew and Ayana, 2017).

Host resistance

Resistant varieties are considered the most economical that provides wide economic importance. However, resistance development's success is commonly influenced by the unavailability of resistance sources, their diversity (Nion and Toyota, 2015). Molecular interactions in the cell walls of resistant with *RS* using a suitable procedure (Dahal et al., 2010). Besides, some resistant tomato genotypes (**Table 3**) have been reported in the country.

Table 3. The reaction of some tomato varieties against *Ralstonia solanacearum* (Alene and Mariam, 2021)

Sl. No	Name of the variety	Reaction for *RS*
1	Awassa	MR
2	Briget 40	R
3	Galilea	HS
4	Venise	R

Note, MR= moderately resistance, R= resistance, HS= highly susceptible

Biological Control (BC)

It is an effective, safe, and environmentally friendly method that has been widely accepted and promoted as a critical practice in sustainable agriculture, with the main potential of the BC being microorganisms such as AMF (arbuscular mycorrhizal fungi) such as Bacillus and Pseudomonas sp. (Tahat et al., 2010). For soil-borne pathogens, BC products have gained recognition in recent years due to the ecological fear of chemical products. Pathogen exclusion, nourishment alteration, cell wall lignifications, and exudation of low molecular weight compounds are among mechanisms involved in controlling and suppressing pathogens by mycorrhizal root fungi (Tahat et al., 2011).

Trichoderma spp. is also reported as one of the most important bioagents for the control of bacterial wilt disease caused by *RS*. For example, Knoppa et al. (2018) found that adding T. asperellum isolates (T4 and T8) to a tomato field delayed disease development and reduced disease by 51-53%. Bora et al. (2015) discovered that combining Trichoderma spp. with other management options significantly reduced bacterial wit incidence (**Table 4**). According to Ibrahim and Alemu's (2017) experimental report, the appliance of Trichoderma isolates on ginger bacterial wilt (*R. solanacearum*) reduced from 40-60% disease incidence.

On the other hand, fluorescent pseudomonades (*Pseudomonas fluorescens*) have been used as plant growth-promoting bacterial strains are reported as promising biocontrol agents for *RS.* Akira et al. (2009)

said that *Pythium oligandrum* is used to control *RS* but not produced and formulated for commercialization.

Table 4. Impacts of *Trichoderma* spp. with the combination of other options in disease reduction and yield improvement

Treatment	Disease reduction (%)	Yield (qt ha^{-1})
Consortia of T. parareesei, T. viride, and P. variotii	26.2	30.8
Consortia of *T. parareesei, T. viride* and *B. thuringiensis*	42.0	58.8
Consortia of *T. parareesei, P. variotii* and *B. thuringiensis*	62.9	74.2
Consortia of *T. parareesei, T.viride, P. variotii, B. thuringiensis* and *C. farmer*	83.9	96.8
COC + Streptocycline	21.0	17.1
Control	-	3.7

Source: modified table of Bora et al. (2015)

Chemical Control

The nature of bacterial wilt pathogen (localization in xylem tissue and soil survival habitation) and unavailability of bactericide chemicals are the current major challenges of bacterial wilt management options by chemicals. However, phosphoric acid (Ji et al., 2005), soil treatments such as soil PH (potential of Hydrogen) modification and application of stable bleaching powder (Mao et al., 2017), and chemical products (Fajinmi, 2010) can all help to reduce bacterial populations and disease intensity. According to Biswal and Dhal (2018) report, the application of 12.5kg/ha bleaching powder before (7 days before) planting reduced bacterial wilt incidence by half and increased tuber yield from 8ton/ha to 18tone/ha.

Integrated management

The combined use of different methods (cultural, host resistance, biological, and chemical application) that are environmentally compatible, economically feasible, and socially acceptable reduces initial inoculums while increasing host resistance, delaying disease onset, and slowing secondary cycles (Nion and Toyota, 2015). Aziz et al. (1992) noted that applications of Bacillus sp. Combining potassium (K) fertilizer reduces bacterial infection on susceptible varieties. It increases plant resistance in moderate resistant varieties because K can serve as an active catalyzer in supporting protein synthesis and carbohydrate formation and makes plants resistant to *RS* attack that multiplies in the xylem.

Integrated use of organic soil amendment using bio-fumigation is one of the essential options to control *RS* effectively via improving soil health. Soil amendment with k fertilizer, soil solarization, and bio-fumigation with lemongrass can reduce the infection induced by secondary inoculums in soil. Integrated use of these components with potassium fertilizer and soil solarization reduces GBW incidence by minimizing the initial inoculum and disease epidemiology rate. This option is not well adopted in Ethiopia (Merga et al., 2019; Prameela and Bhai, 2020).

ENSET AND BANANA BACTERIAL WILT DISEASE

Enset (*Ensete ventricosum*) is a drought-tolerance staple food crop that serves as the driver of the Ethiopian agricultural economy and is utilized by several communities. It can be used as fiber, meal sources for humans (like Kocho, Bulbula, and Amicho), animal forages, construction materials, medicine, and cultural practices (such as soil conservation and enriching plant nutrients) (Zerihun and Temesgen et al., 2014). From different Enset spp. In comparison, the yield obtained from Enset far exceeds that of other serial, fruit and root crops (banana, sweet potato, tomato, etc.) preferred by more than 20% of the Ethiopian population (Yemane et al., 2020).

However, its production and productivity are affected by several biotic and biotic issues such as inadequate research attention, tiresome, diseases (fungal and bacterial wilt diseases, nematodes (Mekuria et al., 2016). Mainly, bacterial wilt disease has seriously affected both enset and banana production widely (Tripathi et al., 2009).

Epidemiology, dissemination and pathogen survival

Enset bacterial [*Xanthomonas campestris* pv. m*usacearum* (*Xcm*)] is the most alarming threat of Enset cultivation on a wide scale with high production risks in Ethiopia (Zerfu et al., 2018; Addis et al., 2008). Optimum temperature (25-30 0C) for its growth is essential. The pathogen enters into the host cells via wounds, pseudostems, and leaves behind lower parts of the host and establishes, colonizes, infect tissues and cause disease rapidly (**Figure 7**) (Aytenfsu and Haile, 2020). The upward movement and infection can occur in the vascular tissues of the rhizome or pseudostem (Blomme et al., 2017).

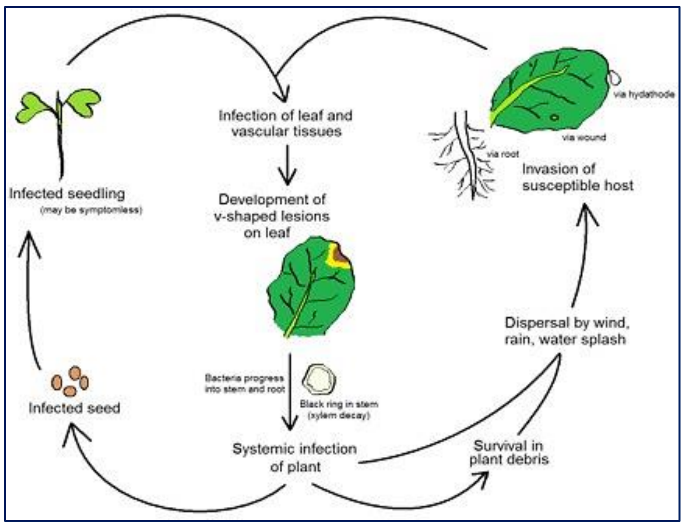


Figure 7. Life cycle of Xanthomonas wilt pathogen (Source: https://www. wikiwand.com/en/*Xanthomonas campestris* pv.campestris)

Once the pathogen established, it can survive in the infected plant debris (Mekuria et al., 2016) and may result in a complete yield loss (Wolde et al., 2016). Pathogen survival in the soil having high moisture conditions (>28%) is longer (two times) than in low soil moisture conditions (Nakato et al., 2018), and the survival period at the field can be longer in the soil than in the plant debris (Aytenfsu and Haile, 2020).

Economic importance and distribution of Enset bacterial wilt (EBW)

Impacts of Xanthomonas wilt (XW) are severe and rapid losses with a gradual increasing rate over the years. Its influence is related to the mother plant's death that contributes to ratoon production cycles (Tripathi et al., 2009; Zerfu et al., 2018). It induces wilting characterized by plants' death, which is the current most serious issue in Eastern and Central African countries (Biruma et al., 2007). EBW is known to cause severe damage via attacking and killing plants by disturbing the whole system with maximum losses mainly at the late maturity stage (**Figure 8**) adapted by Mwebaze et al. (2006).

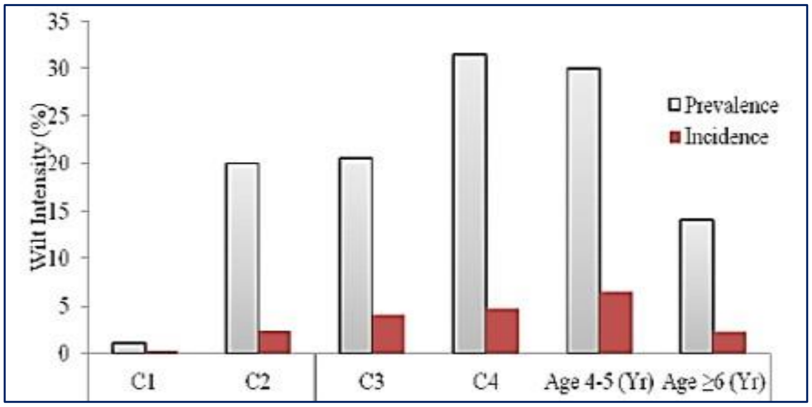
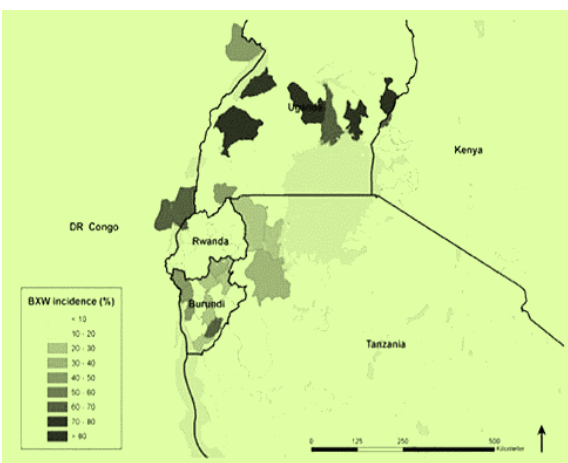


Figure 8. Prevalence and incidence of EBW within different production cycles and ages (Wolde et al., 2016)

First observed in Ethiopia around 1930 (Castellani, 1939), and *Xcm* as the causative agent was identified during 1960 from the Keffa zone (Dangnachew and Bradbury, 1968). Under the natural condition where its epidemics are common, the bacterium can affect bananas as alternate hosts (Dagnachew and Bradbury, 1974). Currently, it has widely distributed and becomes a significant challenge in Central and East African countries and causes up to 100% losses (**Figure 9**) adapted by Nakato et al. (2018).

Figure 9. Enset Bacterial Wilt distribution within different African Countries (Nakato et al., 2018)



Disease symptoms

EBW diagnostic symptoms include leaf yellowing and wilting, droop on older leaves, and dry rot (**Figure 10**). However, symptoms can vary with varieties, crop age. The primary symptoms occur at the center of emerging leaves, cause loss of turgor and wilting, and then spread to the entire plant parts (Thwaites et al., 2000; Tushemereirwe et al., 2004).

Figure 10. Internal (C) and external(A&B) symptoms of bacterial wilt on enset (Blomme et al., 2017)

Disease management options

Cultural control measures

In the place where bacterial diseases are not present, avoiding materials introduction via exclusion is the primary defense line for Xanthomonas wilt diseases. Likewise, the use of disease-free planting materials and good sanitation procedures together with quarantine methods is always essential (Blomme et al., 2017; Geberewold, 2019).

Sanitary measures like avoidance of source of inoculum by uprooting and burring of diseased plants, disinfecting working tools via flaming after use, prevent animals from browsing, and use of disease-free planting materials are essential in controlling EBW (Gezahegn and Mekbib, 2016).

Host plant resistance

Like other attributes (height, yield, and leaf size), pathogens' resistance is a genetically inherited character. This can achieve by the identification of resistance clones via screening. But till now, researchers have tried to develop micropropagation protocols for end-users. It indicates the possibility of producing many *in vitro* plantlets from shoot tip explants (Mulugeta and Tesfaye, 2010; Tariku et al., 2015). For instance, in closely related crops such as bananas, tissue culture is used to eliminate weevils, nematodes, and bacterial diseases (Xanthomonas wilt), Fusarium wilt, and Sigatoka effectively (Blomme et al., 2017).

Conventionally, *Xcm* resistant clones' development was conducted via screening in Ethiopia. For instance, Southern Agricultural Research Institute (SARI) experimented on 89 clones with artificial inculcation. After inoculation (45 days), they develop disease symptoms at various levels with a rapid increase in disease severity (Wolde et al., 2016). Among these, Anikefye, Eminiye, Lemat, and Nechwe showed a relative tolerance reaction to *Xcm*. Dereje (2010) also noticed that no *Xcm* resistance clones were found from 60 evaluated enset clones (Gizachew, 2000).

During the artificial inoculation test, apparent recovery will be observed due to disease development's un-systemic nature. It indicating more detailed and efficient integrated research work is crucial in the future.

Genetic transformation of Enset

To improve superior cultivars without changing clone integrity, genetic transformation confers essential traits to a revolutionary approach. As *Xcm* infects both banana and enset, transgenic-based bacterial wilt disease control in banana can be applicable for enset (Tripathi et al., 2004; Tripathi, 2009). When plants inoculated with bacterial culture artificially, various transgenic lines confirmed complete resistance against *Xcm* (Namukwaya et al., 2012; Tripathi et al., 2015).

Chemical and biological control measures

For disease control, chemicals can give an active response, but their impacts mainly on human health and the environment make it the last option. Streptomycin, Ox-tetracycline, Chloro-amphenicol, and Rifampicin were tested to control the cauliflower's black rot caused by Xcm streptomycin, which offers 100% control (Lenka and Ram, 1997). Also, crude leaf extracts, bract, stem, and root of *Pychnostacisabyssinica* were evaluated for their inhibitory effect on the isolates cannot grow on asparagines medium (Kidist, 2003).

BANANA BACTERIAL WILT (BXW)

Figure 11. Yellowing and wilted leaves

In South and Southwestern Ethiopia, bacterial wilt disease is the most common problem influencing enset and banana production across the production areas (Shimelash et al., 2008).

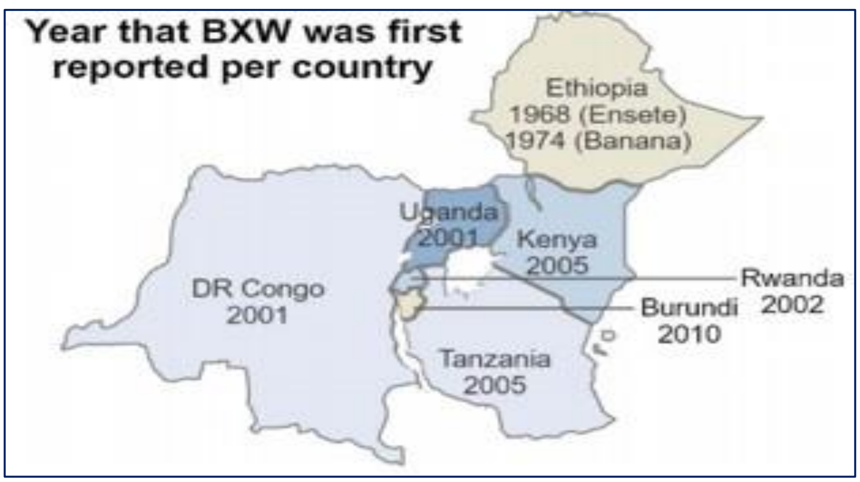


Figure 12. Distribution of Xanthomonas wilt in the tropical African countries (McCampbell et al.,2018)

Regarding its relation with insect vectors and altitude variation, little information is available (**Figure 13**). In Central Uganda, up to 70% yield losses have been reported (Karamura et al., 2006).

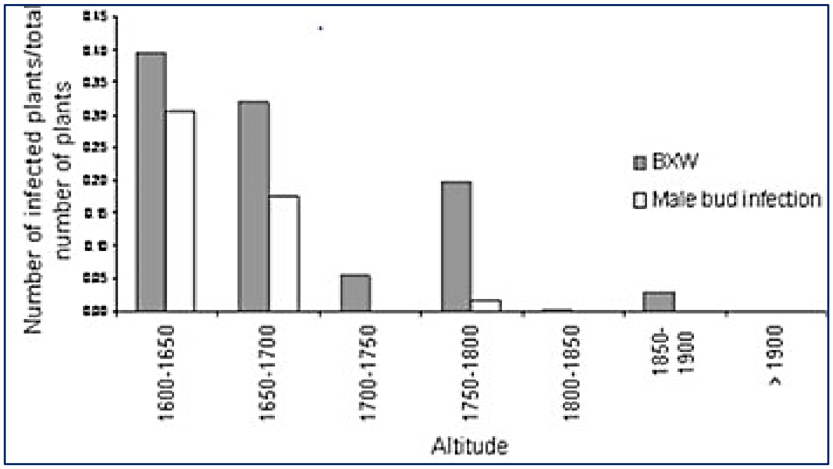


Figure 13. The relationship between altitude and incidence of male bude infection banana with Xanthomonas wilt (Shimelash et al., 2006)

Disease (BXW) management

Diseases have a continuous association with perennial crops that serve as host and inoculum sources for a long time and lead the management to be tiresome and challenging (Ploetz et al., 2007). Bacterial diseases control depends on preventing disease spread, reducing disease impact in affected farms (Bijukya, 2009).

Cultural methods

Cultural practices such as removing the male bud, keep cutting tools clean, cutting down infected plants at soil level, and remove diseased stem are used to avoid insect transmission and reduce the incidence up to negligible levels (Yemataw et al., 2016). Growing varieties having persistent bracts protect the male bud from insect-transmitted infections. Moreover, awareness creation related to its identification (sign and symptoms) and means of transmission management is a crucial way of minimizing the overwhelming impacts of XW in small-scale farms (Geberewold et al., 2019).

CONCLUSIONS AND FUTURE OUTLOOKS

Horticultural crops are the most important crops grown in Ethiopia within various agroecology in smallholders, private commercial farmers, and state-owned large-scale farms. The country's very diverse agroecology is conducive to grow different tropical, subtropical, and temperate fruits and vegetable crops. These crops are high-value commodities and serve as regular sources of income for the poor rural farmers. However, the productions of these crops are seriously affected by several biotic and biotic factors. Mainly bacterial diseases are having to emerge, and re-emerging features are the current severe intimidation.

Bacterial blight of coffee, ginger bacterial wilt, and Enset and Banana wilt diseases caused by *P. syringae*, *R. solanacearum*, and *X. campestris* are the current challenges to essential crop production. The actual killing of their host and yield losses often exceeds 50% from infestations caused by these time-honored pathogens. Emerging and re-emerging plant pathogens are favored with climatic change and become the great confront of crop production today. After it has existed in the reservoirs controlling these bacterial diseases is quite tricky. Hence, to reduce the risks, selecting effective management methods is vital. Also, I will like to forward the message because detailed and compiled research work needs integration among different disciplines; also, bringing the materials that have been worked before can be used as a source of information for further work.

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