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Distribution and Management of Bacterial Wilt (*Xanthomonas Campestris pv. Musacearum*) of Enset (*Ensete Ventricosum*) in Ethiopia: a Review

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ABSTRACT

Enset has high significance in the day to day life of more than 20 million of Ethiopian's as a food source, fiber, animal forage, construction materials, and medicines. However, enset production in the country has been severely affected by bacterial wilt disease of enset (BWE). This review was carried out to investigate the spatial distribution and management options for bacterial wilt of enset, and identify gaps to guide future research. The diseases is widely distributed in major enset growing regions of the country and found to the crop at all developmental stages and lead to losses of up to 100% under severe damage. Currently, over 80% of enset farms are infected by BWE and no enset clone completely resistant to bacterial wilt has been reported. The distribution of the disease varied greatly with altitude having higher disease pressure at higher altitude range than the low altitude. Participatory based integrated disease management (IDM) through collective action approach is reported as a viable option for the successful and sustainable control of BWE. However, different resistant breeding research should be conducted to identify the appropriate resistant gene and to develop resistant clones as other management options.

Keywords: *Bacterial Wilt, Distribution, Enset, Management, Xanthomonas campestris pv. Musacearum.*

INTRODUCTION

Enset [*Ensete ventricosum* (Welw.) Cheesman] belongs to the family *Musaceae* and the genus Ensete. It is monocarpic, herbaceous plant and little researched food crop cultivated only in Ethiopia. The plant is a drought-tolerant and multipurpose crop of which all parts are utilized for different purposes. According to Brandt *et al.* (1997), domesticated enset is planted at altitudes ranging from 1200 to 3,100 m.a.s.l. Most enset-growing areas receive an annual rainfall of about 1,100 to 1,500 millimeters. The average temperature of enset growing areas is between 10 and 21 ℃, and the relative humidity ranges from 63 to 80%; while the wild enset is distributed at an elevation of 1,200 to 1,600 m.a.s.l in Ethiopia (Brandt *et al.*, 1997).

The cultivation of enset is concentrated in the southern and southwestern parts of Ethiopia. It is widely adapted to a range of altitudes, soils, climates and cultivated in the mid to highlands of western Arsi, Bale, SNNPRS and western Oromia including West Shewa, Jimma, Iluba bora and Welega (Brandt, *et al.*, 1997; Genene and Firew, 2016). It is estimated that more than 20 million of Ethiopia's population depends on enset as the staple and co-staple food source, for fiber, animal forage, construction materials and medicines (Zerihun *et al.*, 2013). According to CSA (2017), about 123,479,334.00 of enset trees were harvested in the 2016/17 agricultural season from all over the country and a total production of 2,800,977.87 tonnes, 3,162,563.18 tonnes, 1, 10,060.62 tonnes in the form of *Amicho, Kocho* and *Bula* were obtained, respectively. The average yield of *Amicho*, '*Kocho' and Bula* per plant is 23, 26 and 1 kg, respectively. In the 2017/18 agricultural season, about 2,930, 763.50 tonnes, 3,478, 294.49 tonnes, and 101, 782.16 tonnes of *Amicho, Kocho* and *Bula* were obtained, respectively from a total of 127, 235,588.00 enset trees harvested (CSA, 2018).

Enset has high significance in day to day life of the peasant households cultivating this crop as a staple food. According to Brandt *et al.* (1997) enset

is used as food, cloth, house, bed, cattle's feed and plate for peasants. The edible parts of the plant are the underground stem (corm) and pseudostem, which are pulverized and fermented into a starch-rich product called *kocho*. Enset fiber accounts for more than 30% of Ethiopian fiber production (Abrham *et al.*, 2012).

Although the economic importance of enset is great, its production is affected by several factors, including biotic and abiotic agents, such as diseases, insect pests, weeds, wild animals and soil nutrient depletion, which contribute to low yield and low quality of enset produced. Enset diseases are caused by several bacteria, fungi, viruses, and nematodes. Among these, BWE, caused by *Xanthomonas campestris* pv. *musacearum* is the most important constraint to enset production. Enset bacterial wilt was first reported in 1968 by Dagnachew and Bradbury in Ethiopia and is currently found in all the enset growing regions and on wild enset plants (Brandt *et al.*, 1997).

Table 1 and Figure 1 summarize the most frequently reported enset production constraints and their proportional ranks in the southern part of Ethiopia. Corm rot, porcupine, BWE and Leaf hoper constitute the most important constraints. Farmers also ranked the first most important enset production constraints in their locality from the abovementioned constraints. A large proportion of sample respondents ranked BWE (40.5%) first followed by a porcupine (27.4%) and corm rot (14.3%) (Figure 1) (McKnight-CCRP, 2013).

Table1. *Frequently reported enset production constraints (McKnight-CCRP, 2013)*

Major constraints in enset production	Zone							
	Silti	Gurage	Kembata	Sidamo	Dawro	Gedeo	Wolayta	Total
BWE	32.1	19.4	14.3	66.7	84.4	93.1	90.9	42.3
Enset root millibug	7.1	5.6	49.3	60.0	40.6	56.8	22.7	21.4
Leaf hoper	3.6	2.8	0.0	13.3	37.9	36.4	22.7	11.3
Mole rat	21.4	25.0	7.1	60.0	50.0	4.6	4.5	30.4
Porcupine	25.0	86.1	42.9	63.3	43.8	0.0	0.0	51.2
Swine	0.0	0.0	4.8	20.0	0.0	0.0	0.0	6.0
Corm rot	42.9	83.3	28.6	36.7	78.1	54.4	45.5	54.2
Drought	0.0	8.3	9.5	0.0	0.0	0.0	0.0	4.2

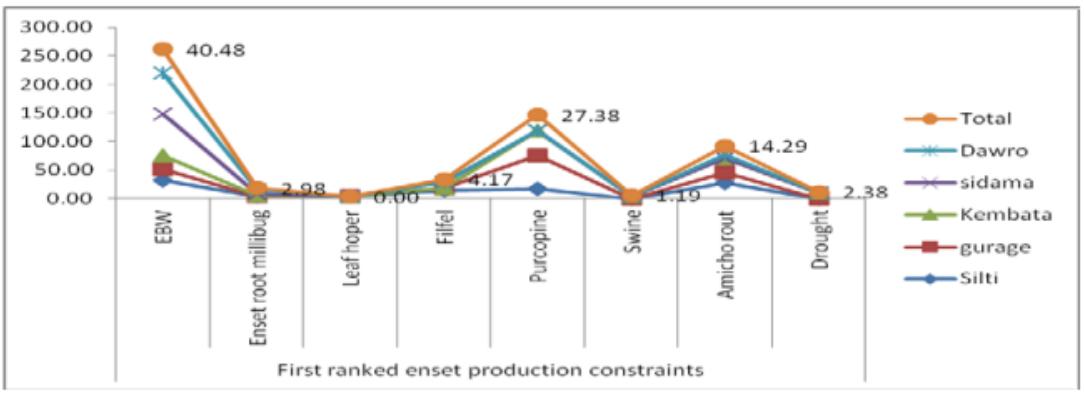

Figure1. *Proportion of sample respondents who ranked enset production constraints first (McKnight-CCRP, 2013)*

The disease is widely distributed in many enset growing regions of the country and affects the crop at all developmental stages (Mekuria, 2013; Mc Knight-CCRP, 2013; Mengistu *et al.*, 2014; Desalegn and Addis, 2015; Fikre, 2017; Ambachew *et al.*, 2018). The results obtained from recent bacterial wilt disease assessment made in some enset fields in SNNPR showed losses of up to 100% under severe damage (Genene and Firew, 2016). Natural epidemics of the disease were also observed in banana fields. Even though the disease is widely distributed and important, there is no intensive work which has been done on the eradication of the disease except some cultural control measures which include collective action campaign by farmers. On the contrary, the farmers are not familiar with the disease symptoms which are sometimes complicated with stress symptoms on plants (Genene and Firew, 2016). A recent study indicated that about 80% of enset farms are infected by BWE. Loss of a single enset plant in a family would mean loss of one man's a day feed. Various preventive and curative management options include applying cultural practices and these measures help in reducing the inoculums load of the pathogen. The use of resistant/ tolerant/ enset clones is one of the best approaches

in the management of BWE, cheaper to farmers and safer to environments (Fikre and Gizachew, 2007). This review was carried out to investigate the spatial distribution and management options for bacterial wilt of enset and identify gaps to considered in the future research directions.

ENSET BACTERIAL WILT

Enset bacterial wilt caused by *Xanthomonas campestris* pv. *Musacearum* is the historical constraint of enset production in Ethiopia, although other biotic, as well as abiotic factors, compromise productivity. The disease was first reported about 52 years ago in Ethiopia on Ensete, which is closely related to banana (Yirgou *et al.*, 1968). BWE has threatened banana production in the Great Lakes region of East Africa including Burundi, Rwanda, the Democratic Republic of Congo, Uganda, Kenya, and Tanzania (Kalyebara *et al*., 2007).

Biology and Epidemiology of Enset Bacterial Wilt

The bacterium is described as a motile, Gram-negative rod, aerobic, possessing a single polar flagellum and producing typical yellow, convex, mucoid colonies on nutrient agar and other media. Cells are straight rods usually with the dimension within the range 0.4 - 0.7 µm X 0.7 – 1.8 µm. The optimum temperature for growth is usually 25-30ºC. *X. campestris* pv. *musacearum* is known to systemically invade all tissues of enset and banana after infection. The pathogen enters the host through wounds on roots, pseudostems, and leaves. This may involve the upward movement of bacteria through the vascular tissues if infection occurs in the lower parts of the plants (rhizome or pseudostem) or the downward movement of bacteria if infection occurs through the inflorescence (Ssekiwoko *et al.*, 2006; Blomme *et al.*, 2007). Once it has entered the plant, the pathogen is able to establish and cause disease rapidly provided the bacterium is received on a receptive infection court (wound, recently dehisced bract, etc.) in a viable state and the environment is conducive to infection and tissue colonization. In regions suitable for banana and enset cultivation, environmental conditions are likely to be conducive to disease development (Smith *et al.*, 2008). After the establishment of the disease in the plant, it can spread by different mechanisms to new fields.

Host Range and Major Symptom

The disease also attacks banana and other *Musa* spp. (Viljoen, 2010). The disease attacks almost all varieties of commonly grown banana cultivars and *enset* clones (Tripathi *et al.*, 2007; Gizachew *et al.*, 2008). Aritua *et al.* (2007) reported that Xcm may have the potential to infect maize, sugarcane, and sorghum; therefore, these plants may act as alternative hosts and reservoirs for infection. Artificial inoculation of maize also developed symptoms of Xcm *Cannaceae, Costaceae, Heliconiaceae, Marantaceae, Strelitziaceae,* and *Zingiberaceae* are considered as host plants for the pathogen and could be possible sources of inocula for the pathogen (Karamura *et al.*, 2008). Pathogenicity tests were carried out to determine the possible host range of the pathogenic *Xcm* and the reaction of various plant species, namely cultivated enset, wild enset, *Canna* species and cereal crops (maize, sorghum, and finger millet) and revealed that there are also other potential alternative hosts for the pathogen apart from cultivated enset and banana crops (Alemayehu *et al*., 2016). According to Alemayehu *et al*. (2016), typical bacterial wilt symptom such as yellowing from the apex to the edge of the inoculated leaf, water-soaked lesions along the inoculated leaf's midrib, a leaf necrosis and discoloration finally turning wilting and dryness was observed in wild enset, *canna* spp., maize, sorghum, and finger millet varieties after two to four weeks after inoculation depending on the plant tested.

Bacterial wilt attacks enset at any stage of growth, including full maturity (Brandt *et al.*, 1997). The initial symptoms of the disease occur on the central leaf and spread to all parts. Bacterial ooze exudes when non-dry part of the plant is removed. A typical bacterial wilt symptom in enset plants older than two years is that the innermost leaf sheaths become yellowish and droop. In the leaf, the earliest symptoms are usually loss of turgor and wilting in the spear (youngest emerging leaf) preceded by yellowing and distortion, especially in young plants. Internally vascular bundles show a cream, yellow or pinkish discoloration that may extend throughout the plant but are often most pronounced in the floral raceme. The large air spaces within the leaf bases become filled with pockets of cream to pale yellow ooze and this characteristics feature appears to distinguish *Xanthomonas* wilt from other bacterial wilts of banana. In banana, infection of corm may spread into daughter suckers, or in enset into plantlets induced by the removal of the vegetative meristem (CABI, 2005). A cut made through the petioles of

newly infected enset plant reveals browning of the vascular strands and yellowish or grayish masses of bacterial ooze come out from strands (Tripathi *et al.,* 2009). The ooze exudes within a few minutes after cutting the tissue and abundant quantities may be produced over a period of several hours (Fikre *et al.,* 2012). Yellow or brown streaks occur in the vascular tissues of infected plants. Eventually, infected plants wither and the plant rots. Symptoms seem to progress faster during the wet season than during the dry season. The time taken to reach different stages of symptom expression may differ with cultivar and environmental conditions, but plants show symptoms within three weeks of infection (Tripathi *et al.,* 2009). In the banana crop, infected plants also develop symptoms characterized by a progressive yellowing and wilting of leaves, with fruits ripening prematurely and unevenly with internal brown discoloration. When stems are cut, a pocket of pale yellow bacterial ooze appears within 5-15 minutes. Yellow or brown streaks occur in vascular tissues of the infected plants. Other symptoms on the floral parts include wilting of bracts, shriveling and rotting of the male buds, and flower stalks turning yellow-brown. Plant death commonly results from the infection (Tushemereirwe *et al*., 2004).

Survival and Dissemination

Once established in an area, the disease spreads rapidly and results in total yield loss (Welde-michael, 2008a). The disease mainly spreads through infected farm tools, infected planting materials (since the plant requires repeated transplanting that damage the corm and roots), animals that fed on infected plants and possibly insects feeding on the foliage (Welde-Michael *et al.*, 2008). Investigations made by Mwebaze *et al*. (2006) to determine the survival of the pathogen in the soil indicate that the pathogen can survive longer (two times) in high moisture conditions (28%) than in low soil moisture conditions. In addition, its survival period in the field would be longer in the soil than in the plant debris. He concluded that the survival of the pathogen is mainly through infected plant debris and infected soil. Handoro (2014) also reported that *Xcm* can survive in *Kocho* for more than 14 weeks. According to Yigou and Bradbury (1974), long-distance transmission of the disease is aided through contaminated farming tools such as pruning knives which transmit the bacteria through injuries on the roots and aerial parts, and movement of infected plant materials (suckers, bunches, leaves).

The major transmitters of BW are insects as they move from one plant to another looking for nectar in flowers (Sekiwoko *et al*., 2006). Ambachew *et al*. (2018) also observed a higher positive interaction with the presence of leafhopper and practice of intercropping with BWE incidence as disease incidence would go up by 39.5 and 16.9% in every unit increase in leafhopper and intercropping practices, respectively. This was due to the presence of leafhoppers almost in all surveyed and infected farms and their movement within the field facilitates disease transmission from infected to the healthy plant by holding the bacteria on their entire body (Ambachew *et al*., 2018).

Bacterial wilt is easily spread by any object touching the contaminated parts of the plant or processed enset like *kocho*. Contaminated cutting and processing tools, in particular, spread the disease. Cutting enset leaves for animal feed and wrappers may spread the disease from one plant to another. Garden tools play a major role in the mechanical transmission of bacterial wilt and that for mechanical transmission to occur, fresh injuries are necessary (Addis *et al.,* 2010). Animals that feed on the rhizome, such as the aardvark and porcupine, have been implicated in the local spread in enset gardens of Ethiopia (Thwaites *et al.*, 2000).

Prevalence and Incidence of Bacterial Wilt of Enseto in Ethiopia

According to the report of McKnight-CCRP (2013), the distribution of disease and its level of damage were variable in eight major enset growing Zones of southern Ethiopia; namely Guragie, Siltie, Dawuro, Sidama, Wolayita, Gedeo, Hadyia, and Kembata. The highest (78.7%) and lowest (3.3%) prevalence rate was recorded in Gedeo and Kembata zones respectively. BWE distributions were highest in Gedeo, Dawro, Sidama, Silti, Wolayta and Gurage Zones. The proportion of enset infected with BWE per individual holding (severity) has also been computed. The highest enset damage was recorded in Wolayta (20.8%) followed by Dawro (20.2%), Gurage, (17.7%), Gedeo (16.9%), Sidama (13.8%) in 2012/13 (Table 2).

Table2. *Proportion of enset bacterial wilt disease prevalence and severity (McKnight-CCRP, 2013)*

Infected plant in 2012/2013		Zone							Total
		Silt	Gurage	Kembata	Sidama	Dawro	Gedeo	Wolayia	
	yes	23.3	13.5	3.3	31	52.6	78.7	21.3	27.8
	No	76.7	86.5	96.7	69.0	47.4	4.3	27.3	72.2
Mean of infected enset		10.2	38.0	8.7	135.5	141.2	44.8	15.1	128.3
Mean of matured enset in field		345.8	214.3	558.7	982.7	699.8	265.5	72.6	448.4
Proportion of Enset infected/Field		3.0	17.7	1.6	13.8	20.2	16.9	20.8	28.6

Mengistu *et al.* (2014) have also carried out a field survey of BWE disease in the main growing season during September-November, 2012 at two major enset growing areas of the Tikur Inchini and Jibat districts of West Shewa, Ethiopia. They have assessed a total of 75 enset cultivated fields from Tikur Inchini district, of which, 67 fields were affected with a mean disease prevalence of 89.3%. From Jibat district, a total of 75 enset cultivated fields were assessed, of which, 65 fields were affected with a mean disease prevalence of 86.7%. Their findings indicated that the disease was economically important to the community of Tikur Inchini and Jibat districts (Table 3).

Table3. *Incidence and prevalence of enset bacterial wilt disease in cultivated fields (Mengistu et al., 2014)*

Locality	No. fields inspected	Altitude(m.a.s.l)	Mean prevalence (%)	Mean Incidence (%)
Tikur Inchini district				
Waldo Hindhe	15	2478-2494	93	27
Bola Germama	15	2449-2584	93	26
Bola Roge	15	2521-2613	86.7	20
Bola Demeke	15	2520-2600	93	19
Homi Hane	15	2462-2490	80	14
Jibat district				
Munyo Abayi	15	2498-2571	93	25
Maru Gombo	15	2409-2444	86.6	16
Bilo Malima	15	2460-2795	93	22
Tutu Jibat	15	2526-2585	86.6	15
Munyo Witate	15	2455-2575	80	14

Mengistu *et al.* (2014) have also assessed the prevalence and incidence of BWE disease in different altitude ranges of enset cultivated fields and the highest prevalence, 89% of enset bacterial wilt was recorded at the lower elevation of 2300 to 2500 m.a.s.l followed by 88% prevalence at 2,500 to 2,700 m. a. s. l (Table 4).

Fikre (2017) surveyed a total of hundred enset fields to determine BWE incidence and distribution in the highland of Gedeb *Woreda* and about 93% of assessed enset fields were at high BW incidence. He concluded that BWE disease was the most important and serious challenge for enset production and productivity. Similarly, Desalegn and Addis (2015) were carried out a survey study in Borana zone in the year 2014 and 2015, and they have observed bacterial wilt disease symptoms in the majority (33% and 56%) of the inspected enset fields, respectively (Table 5 and 6). They explained that disease prevalence and incidence varied among the districts and peasant associations within a district. They computed a range of disease incidence from 0-50.5% and 0-29.5% with a mean of 29.46% and 12.89% in the year 2014 and 2015 respectively. Incidence (%) equaled to stand loss (%) because of the fact that the infected plant will not recover and the diseased plant is not used by the community for any purpose.

Therefore, on average 21.17% of enset stands were lost due to BWE (29.46% and 12.89% in the year 2014 and 2015, respectively).

Table4. *Prevalence and incidence of enset bacterial wilt disease in different altitude ranges (Mengistu et al., 2014)*

Altitude Range (m.a.s.l)	No.of fields inspected	Prevalence (%)	Incidence (%)
2300-2500	69	89	32
2500-2700	77	88	31
2700-2900	4	75	18
Total	150		

Table5. *Survey on Enset Bacterial wilt disease in Boranamid-highlands in 2014 (Desalegn and Addis, 2015)*

District	PA[a]	No. field			Prevalence (%)	Incidence (%)
		OB[b]	DF[c]	DS[d]		
Abaya	Guangua	10	10	0	0	0
	Samaro	10	6	4	40	30
	Tureqajima	10	6	4	40	10
Bule-hora	Gaerba	10	6	4	40	18.8
	Muriturquma	9	6	3	33	53.3
	Qillenso	10	4	6	60	44.2
Galana	Qarsa	9	8	1	11	10
	Tore badiya	10	5	5	50	48.3
	Samalo	9	3	6	67	50.5
	Grand total	87	54	33	38	
Average						29.46

[a]*P A:Peasant association,* [b]*OB: Observed,* [c]*Disease free,* [d]*DS: Diseased*

Table6. *Survey on enset bacterial wilt disease in Borana mid-highlands in 2015 (Desalegn and Addis, 2015)*

District	PA[a]	No.field			Prevalence (%)	Incidence (%)
		OB[b]	DF[c]	DS[d]		
Abaya	Guangua	10	10	0	0	0
	Samaro	10	8	2	20	5
	Tureqajima	10	2	8	80	7.5
Bule-hora	Dogobulchani	10	1	9	90	2.1
	Dogosodu	10	0	10	100	13
	Era-lipitu	10	3	7	70	25
Galana	Cerkata	10	7	3	30	10
	Qarsa	10	6	4	40	5
	Samalo	10	0	10	100	29.5
	Grand total	100	44	56	56	
Average						12.89

[a]*P A:Peasant association,* [b]*OB: Observed,* [c]*Disease free,* [d]*DS: Diseased*

The survey was conducted in Gurage, Hadiya, and Sidama zones of SNNPRS in the 2012/2013 growing season on 270 enset fields and about 34.81% enset fields were affected by the disease (Mekuria, 2013). He reported that the disease was widely distributed and detected in all agro-ecologies and locations even if the disease was most prevalent in Hadiya Zone with 42.22% prevalence followed by Gurage and Sidama Zones with the prevalence of 35.56% and 26.67%, respectively. According to Mekuria (2013), there was variation in BWE prevalence across altitudes with the disease being most prevalent (50%) in at an altitude range of 2000-2500 m.a.s.l followed by >2500 and <2000 m.a.s.l with an average prevalence of 36.67% and 16.67%, respectively (Table 7). He also compared BWE prevalence between cropping practices and about 30.58% of intercropped fields and 36.93% of monocropped fields were infected with the disease.

Table7. *The mean incidence and prevalence of enset bacterial wilt in different production locations (Mekuria , 2013)*

Variables	Variable class	NIF	Prevalence (%)	Incidence			
				Max.	Min.	Mean	SD.
Total		94	34.81	28.57	0	3.89	6.15
Zones	Gurage	32	35.56	16.67	0	3.21	4.93
	Hadiya	38	42.22	28.57	0	5.56	7.44
	Sidama	24	26.67	22.22	0	2.89	5.49
Altitude	<2000	15	16.67	17.24	0	1.91	4.37
	2000-2500	45	50	28.57	0	5.81	7.27
	≥2500	33	36.67	20	0	3.93	5.87
Woreda	Edja	14	46.67	16.67	0	4.1	5.57
	Cheha	6	20	10.34	0	1.52	3.17
	Gumer	12	40	15.79	0	4	5.39
	Aletachiko	2	6.67	11.43	0	0.74	2.81
	Wonsho	9	30	22.22	0	3.05	5.67

	Lemo	23	76.67	28.57	0	10.31	8.21
	Hula	13	43.33	20	0	4.86	6.61
	Misha	7	23.33	16.3	0	2.93	5.56
	Gibe	8	26.67	17.24	0	3.46	6.05

NIF: Number of infected field, Max: Maximum, Min: Minimum, SD: Standard deviation

Mekuria (2013) explained that the mean incidence of BWE varied for different variables and variable classes (Table 6 and 7). He reported that bacterial wilt could infect enset at all cycles and growth stages, but minimum disease prevalence occurred in cycle 1 where only 1.11% of the surveyed fields were affected by the disease and higher (30%) disease prevalence was recorded at age of four to five (Table 8). On the other hand, higher disease prevalence (36.89%) was recorded on fields with less than or equal to five clones per enset fields, while 33.53% of enset fields containing greater than five clones were affected by the disease. This indicates that the diversity of enset may help to restrict the transmission of the disease. The distribution of the disease also varied greatly with altitude groups, with the mid- and high-altitudes having higher disease pressure than the low altitude. Bacterial wilt incidence at the whole field was at a maximum in narrow spacing (≤ 1.5x1.5 m) than in wider spacing (≥ 1.5x1.5 m) with an incidence of 4.53 and 3.39%, respectively.

Likewise, the mean incidence in cycle 4 with narrow (≤ 1.5x1.5 m) spacing was at maximum with 5.33% wilt incidence, while only 4.30% of enset plants at cycle 4 were infected in widely spaced (≥1.5x1.5 m) enset fields. This might be attributed to higher disease transmission in narrow spacing, because of suffocation, humid microclimate and physical contact, which aggravate disease spread (Mekuria, 2013).

Table8. *The mean incidence and prevalence of enset bacterial wilt for different variables (Mekuria, 2013)*

Variables	Variable class	NIF	Prevalence (%)	Incidence			
				Max.	Min.	Mean	SD.
Cropping cycle	Cycle1	3	1.11	20	0	0.2	1.87
	Cycle2	54	20	40	0	2.48	6.95
	Cycle3	37	20.56	40	0	4.13	8.93
	Cycle4	85	31.48	37.5	0	4.75	7.92
Age (Year)	4-5	81	30	57.14	0	6.55	11.32
	≥6	38	14.07	33.33	0	2.37	6.25
Cropping system	Intercrop	29	30.85	21.62	0	3.61	6.01
	Mono crop	65	36.93	28.57	0	4.04	6.23
Spacing at Cycle4(m)	>1.5x1.5 m	50(43)	32.9(30.3)	21.62(23.81)	0	3.39(4.3)	5.46(7.17)
	≤1.5x1.5 m	44(41)	37.2(33.1)	28.57(37.5)	0	4.53(5.33)	6.9(8.79)
	≥1x1	18	19.35	33.33	0	3.7	8.16
	<1x1	19	21.87	40	0	4.58	9.71
Field size(ha)	>0.25	43	30.71	25.81	0	3.22	5.72
	≤0.25	51	39.23	28.57	0	4.6	6.52
Total harvest/year/	≥50	13	17.57	12.5	0	1.28	3.3
	31-49	34	37.36	20	0	3.88	5.65
	≤30	47	44.74	28.57	0	5.73	7.44
Priority of enset	1st	80	32.92	28.57	0	3.66	6.02
	2nd	12	54.54	22.86	0	6.45	7.36
	3rd	2	40	10.71	0	3.62	5.09
No. of clone	≤5	38	36.89	22.2	0	4.19	6.22
	>5	56	33.53	28.57	0	3.7	6.11

Data in parenthesis is for cycle 4, NIF: Number of infected field, SD: Standard deviation

A recent survey by Ambachew *et al*. (2018) also confirmed that the BWE disease was widely distributed in all assessed areas of Yem special districts of Southern Nations, Nationalities, and Peoples' Regions state (SNNPRs) of Ethiopia. They reported that out of 200 fields surveyed, about 91.5% (183 farms) of farms were showed typical enset bacterial wilt disease symptoms with different levels of magnitude (Ambachew *et al*., 2018).

Management of Bacterial Wilt of Enset

Being a bacterial disease, BWE is difficult to control once established due to the lack of an effective chemical or other curative treatments (Biruma *et al.*, 2007). Handoro *et al*. (2012)

reported cultural practices and sanitation control measures are the most principal control measures for BWE. On the other hand, good sanitation (removal of infected plant and plant parts), curative mechanisms, use of disease-free sucker for planting material, crop rotation, use of resistant clones can serve as viable management options for bacterial wilt of enset. The identification and early removal of infected plants a key part of the control system (Karamura *et al.*, 2008).

Reaction of Enset Clone to Bacterial Wilt

Fikre and Alemar (2016) evaluated the reaction of 80 corms of enset clones to *Xanthomonas campestris* pv. *musacearum* and obtained significant differences in reactions to the bacterial wilt pathogen. All the tested enset clones showed initial yellowing symptoms on the inoculated leaves after 27 (on susceptible) to 45 (on resistance/ tolerant) days after artificial inoculation (Table 9).

Table9. *Enset clone responses to bacterial wilt under artificial inoculation (Fikre and Alemar, 2016).*

Group	Reaction Type	Average Disease infection (%)	No. of *enset* clone
I	Resistant	0-20	18 (+check)
II	MT/MS	21-60	18
III	Suceptible	>60	44 (+check)

MR=moderately tolerant, MS=moderately susceptible

According to Fikre and Alemar (2016), none of the clones are found to be free from the BW disease symptoms and concluded that there is no enset clone completely resistant to bacterial wilt disease. The enset clones with low BW disease infections (0-20%) can be considered as resistance/tolerant to the pathogen, whereas the enset clones showed a high percentage of severity index (60-100%) were identified as highly susceptible to BW pathogen and the disease development was fast on the susceptible enset clones, whereas comparatively slow progress on the resistance/tolerant enset clones. The AUDPC value also revealed that group one (18 enset clones) was the most resistant/ tolerant to bacterial wilt, while the group three (44 enset clones) was the most susceptible and the remaining enset clones (group two) comprising intermediate reactions to the pathogen (Figure 2).

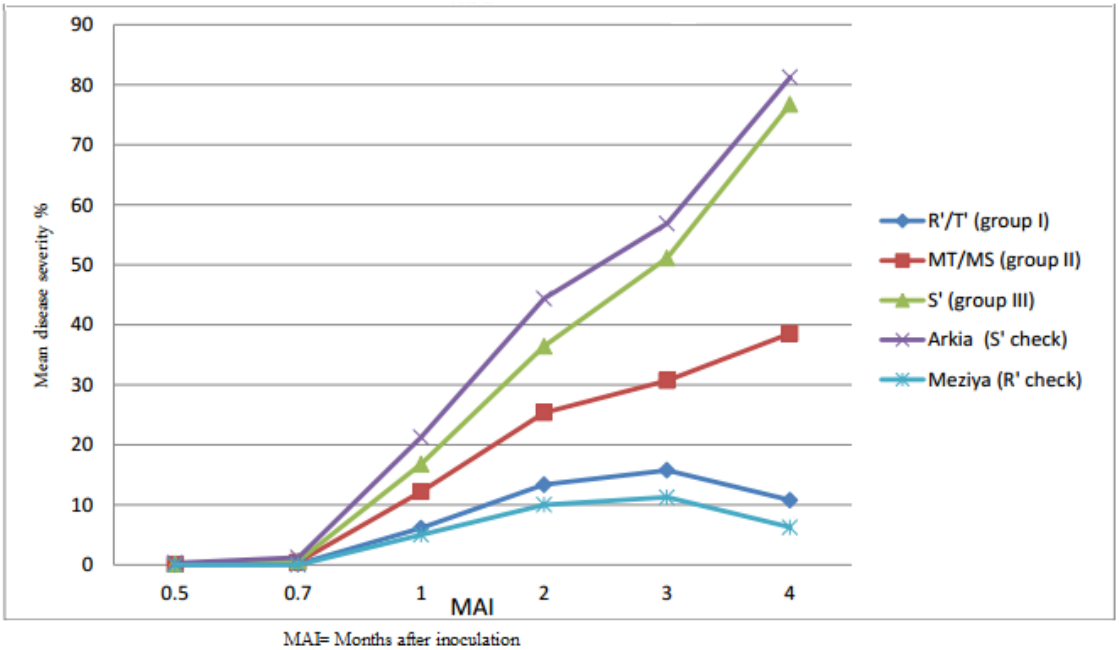

Figure3. *The Progression of BW disease severity over time after artificial inoculation (Fikre and Alemar, 2016)*

Mekurria *et al.* (2016) evaluated 25 enset clones for their reaction to Xcm pathogen under artificial inoculation and all of the clones showed symptoms of BWE at different assessment periods, while all the control plants inoculated with water did not show any wilt symptoms in all clones and at all assessment periods. Besides, none of the evaluated enset clones was immune to the pathogen. The various enset clones showed significant differences in susceptibility to Xcm. The wilt incidence at the 35th DAI ranged from 0 to 100% for the evaluated enset clones. Gezwet was the only resistant clone to Xcm with no wilt incidence at 35 DAI (Figures 1), and with a mean incubation period of 42.2 days and complete wilting of 71 days. Seven enset clones, namely Gimbwe, Terye, Agade,

Yeshrakinke, Kechere, Badedat, and Ferezye, were moderately resistant to Xcm. These clones showed a wilt incidence of less than 40% at 35 DAI and an incubation period of 37.9-40.9 days. On the other hand, a complete wilting for these clones ranged from 63-70 DAI (Table 10).

Table10. *Mean incubation period, complete wilting, incidence at 35 DAI and disease rating (Mekurria et al., 2016)*

Clone name	No.IP[a]	I35[b]	Mean Incu[c]	Compt[d]	Clone reaction rating
Gezwet	10	0^{h}	42.2^{a}	71^{a}	R
Gimbwe	10	10^{hg}	40.9^{ba}	66^{bac}	MR
Terye	10	20^{fhg}	38.5^{bac}	67^{bac}	MR
Agade	10	30^{fheg}	39.5^{bac}	63^{bdac}	MR
Yeshrakinke	10	30^{egdf}	39.8^{bac}	70^{ba}	MR
Kechere	10	30^{egdf}	37.9^{edbac}	64^{bdac}	MR
Badedat	10	30^{egdf}	38.6^{bac}	68^{bac}	MR
Ferezye	10	33.3^{feg}	38^{bdac}	67.8^{bac}	MR
Kibinar	10	40^{fdeg}	32.6^{ebdgef}	63.0^{bdac}	S
Yegendeye	10	50^{fdec}	38.5^{bac}	70^{ba}	S
Zober	10	50^{bdec}	$34.8^{ebdagef}$	62.2^{bdec}	S
Ewane	10	60^{bdec}	$34.3^{ebdagef}$	56^{fdeg}	S
Wenadeye	10	60^{bdec}	31.6^{edhgef}	60^{fdec}	S
Astara	10	60^{bdec}	$31.2^{eidghef}$	66^{bac}	S
Beresye	10	70^{bdac}	29.5^{eidhgf}	53.6^{fhg}	HS
Shebrat	10	70^{bdac}	29.5^{eidhgf}	52.4^{fhg}	HS
Teguaner	10	70^{bdac}	35.7^{ebdacf}	53.2^{fhg}	HS
Demolejat	10	70^{bdac}	29.2^{eihgf}	62^{bdec}	HS
Nechwe	10	80^{bac}	22.8^{ij}	51.4^{hg}	HS
Kanchwe	10	80^{bac}	28.1^{ihgf}	55^{fheg}	HS
Yekeswe	10	90^{ba}	27.8^{ihgf}	54^{fhg}	HS
Bushrat	10	100^{a}	26.7^{ihg}	63^{bdac}	HS
Oret	10	100^{a}	23.8^{ihj}	64^{bdac}	HS
Lemat	10	100^{a}	18.4j	57.4^{fdeg}	HS
Yeregye	9	100^{a}	16.2^{j}	47.8^{h}	HS

[a] *Number of inoculated enset plant;* [b] *Wilt incidence at 35 days after inoculation;* [c] *Incubation period;* [d] *Mean complete wilting date after inoculation; R, Resistant; MR, Moderately resistant; S, Susceptible; HS, Highly susceptible; Means with different superscripts within the same column and class are statistically different at 5% level of significance according to DMRT.*

Disease progress was rapid on highly susceptible and susceptible clones, whereas relatively slow progress was recorded on resistant and moderately resistant enset clones (Figure 3). Similarly, the disease progress curve was steeper initially for resistant and moderately resistant clones, while it increased faster for the susceptible and highly susceptible enset clones (Mekurria *et al.*, 2016).

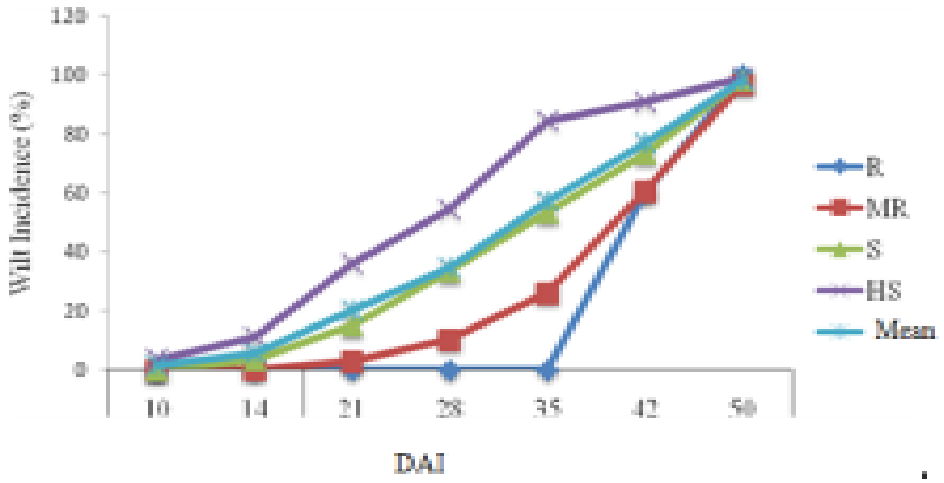

Figure3. *Mean disease progress curve for resistant (R), moderately resistant (MR), susceptible (S) and highly susceptible (HS) clones as compared to the average (Mean) progress curve (Mekurria et al., 2016).*

Effects of Plant Extracts and Other Materials against Bacterial Wilt Isolates

Daniel and Getaneh (2015) compared the antibacterial activities of botanical plant extracts, 'Goat urine', 'salt', control group and standard antibiotic (Penicillin) and among them standard check antibiotics (Penicillin) have shown strong antibacterial activity against *Xanthomonas campestris* pv *musacearum* isolate than other treatments with an inhibition zone of 21.02 mm followed by *Etecha* + *Kabericho* with 14.05 mm zone of inhibition under in vitro condition. The combination of *Etecha* + *Kabericho*, individual plant extract *Etecha*, and a combination of Solle+ Hidafite + Tembosuse are important for the control of *Xanthomonas campestris* pv. *musacearum* isolate in vivo condition and these variations could be due to the active ingredient or phytochemical differences between species extract and other material.

According to Daniel and Getaneh (2015)**,** botanical extracts from some plant parts showed promising effects against bacterial isolate. However, the antibacterial activity of many treatment combinations showed a weak antibacterial activity against the bacterial growth as a comparison with a standard antibiotic (Penicillin) with inhibition zone range between 7.10 – 9.87mm. The single plant extract such as Tembosuse, Hidafite, Kabericho, Solle, Goat urine, Salt and combination of Hidafite + Salt, Tembosuse + Urine, Solle + Salt, Solle + Urine, Solle + Tembosuse, Tembosuse + Salt, Tembosuse + Etecha, Urine + Salt, Hidafite + Tembosuse were not significantly different among treatments and they didn't show any antibacterial activity against the isolate at an equal concentration of the combinations. The combination of treatments may have neutralized the active ingredients so much and/or also the chemical compounds in the extracts might not have a synergetic effect against the isolate.

Mekuria (2013) tested the sensitivity of *X. campestris* pv. *musacearum*, to five antibiotics (amoxicillin, tetracycline, chloramphenicol, streptomycin sulphate, and gentamycin) and revealed that there was variation among the antibiotics in the inhibition of bacterial culture growths of Xcm for Gurage and Hagere Selam isolates. All the antibiotics significantly reduced the multiplication of both Xcm isolates as compared to the control but they varied greatly in their effects. Tetracycline was effective against both isolates. In contrast, gentamycin and streptomycin sulphate were found to be the least effective antibiotics against both isolates. For both isolates, as the concentration of antibiotics increased from 0.1 to 1%, the inhibition zones also increased. Amoxacillin was found to be the most effective antibiotics in inhibiting the growth of Gurage isolate, but it was moderately effective against HS isolate. Gentamycin was found to be the least effective antibiotics in inhibiting the growth of Gurage isolates of Xcm with an inhibition zone of 1.1 cm followed by CAPH and streptomycin sulphate which were comparatively moderately effective against Xcm with the diameter of inhibition zones of 2.12 and 2.13 cm, respectively. For HS, the maximum diameter (3.87 cm) of inhibition zone was observed due to tetracycline at a concentration of 1% and the minimum (0.40 cm) was for streptomycin sulphate at 0.1% concentrations (Table 11).

Table11. *Inhibition zones of antibiotics against growth of Gurage and Hagere Selam isolates (Mekuria, 2013)*

Inhibition Zones(cm)								
Antibiotics	**Gurage**				**Hagere Selam**			
	Rate (%)				**Rate (%)**			
	1	**0.5**	**0.1**	**Mean**	**1**	**0.5**	**0.1**	**mean**
Amxacillin	3.87^{a}	3.07^{cd}	2.7^{cbc}	3.21^{a}	1.63^{dc}	1.43^{c}	0.8^{g}	1.29^{b}
Tetracycline	3.2b	2.97^{cbd}	2.23^{g}	2.83^{b}	2.73^{a}	2.47^{b}	1.73^{c}	2.31^{a}
Chloramphinicol	2.63^{fed}	2.3^{fg}	1.43^{ih}	2.12^{c}	2.47^{b}	2.63^{ba}	1.73^{c}	2.28^{a}
Strept.sulphate	2.47^{feg}	2.17^{g}	1.76^{g}	2.13^{c}	0.77^{g}	0.67^{hg}	0.40^{i}	0.61^{d}
Gentamycin	1.47^{ih}	1.3^{i}	0.53^{j}	1.1^{d}	1.47^{dc}	1^{f}	0.57^{hi}	1.01^{c}
Control	0.00^{k}	0^{k}	0^{k}	0^{k}	0^{j}	0^{j}	0^{k}	0^{k}
Mean	2.27^{a}	1.97^{b}	1.44^{c}		1.51^{a}	1.37^{b}	0.87^{c}	
LSD (0.01%)	0.39	0.16	0.26		0.086	0.21	0.12	
CV (%)				9.28				7.51
SEM±				0.18				0.09

LSD, Least Significant Difference; CV, Coefficient of variation; SEM, Standard Error of Means; Means with different superscripts within the same column and class are statistically different at 1% level of significance.

Integrated Managements of Bacterial Wilt of Enset

Several strategies like using only healthy and clean planting materials (suckers or transplants), applying sanitary control measures (destruction of the infected plants/debris and sterilization of farming/pruning tools), cultural practices including crop rotation, plant spacing, de-budding and use of resistant varieties are suggested for reducing the inoculum load of the pathogen and to minimize the damage. Application of these measures could help to reduce the pathogen load and the development as well as the spread of the disease. If not controlled quickly, the disease may attain epidemic levels. Long term sustainable control of the disease will also change in the mindsets of farmers and the extension agents. This could be attained through training and improving public awareness about the importance of the disease. In the long term, it is necessary to integrate *Xanthomonas* wilt control in the national and/or regional integrated pest and disease management programs such as farmer field schools where participatory management approaches involving different service providers share their experiences and knowledge for the control of the disease (Fikre, 2009).

A case study was conducted in the highland of Gedeb Woreda between 2014 and 2016 cropping seasons to scaling up an IDM through collective action at the community level with suitable bacterial wilt control events include sanitary control measures, improved cultural practices, disease-free and tolerant enset clones (Fikre, 2017). He also collected baseline information about pre and post-intervention to understand the farming community's perception towards the BW behavior, causal agent, means of dissemination and traditional knowledge to control the BW disease. According to Fikre (2017), farmers have considerable indigenous knowledge of enset production system, clonal selection for various values. However, the initial knowledge of farmers on the bacterial wilt disease causal agent, mode of transmission and control measures has been negligible. Accordingly, subsequent training on improved enset production and bacterial wilt management practices have been given for a total of 124 representatives including officials of woreda and kebele, extension service experts, CBO leaders such as religion, *idir*, *iqub*, respected local elders and elites, model farmers, school director, women, and youth affairs.

The expectation of the chemical control method was limiting farming community from implementing non-chemical control measures during their initial discussions as they had negative attitudes about the effectiveness of the sanitary control measures and cultural practices. Regarding the use of chemicals, for the control of enset BW, it is not yet investigated well, because of chemical control method is likely infeasible for BW control in enset. However, after subsequent sensitizations and awareness creation training including demonstration of BW control measures, the farming community understood the scientific approach and developed trustful knowledge on the effectiveness IDM started to practice through collective action. The reason for the importance of collective action is that uprooting and disposing of infected enset plants from enset fields into pits demand more labors and times that it is very difficult for some households having a small size of the family. Implementing of sanitary control measures such as uprooting and burying in dug pits outside the enset fields and/or burning with fire, disinfecting farming, as well as *kocho* processing tools with fire flame, were used during collective action of BW eradication (Figure 4). Because of the permanent nature of enset plantation**,** it is difficult to apply crop rotation on the whole enset field (Fikre, 2017).

Figure4. *Destruction and disposal of diseased plants (Fikre, 2017)*

Finally, the majorities of the farmers (89.33%) were become aware of BWE disease behavior and adopt the effectiveness of IDM in checking BW disease (Table 12). This indicates that participatory based IDM through collective action approach is a viable option for the successful and sustainable control of enset BW as it involves suitable control components and different partners along with farming communities (Fikre, 2017).

Table12. *Comparative results of farmers' knowledge and perception on BW disease (Fikre, 2017)*

Description	Pre-intervention (%)	Post-intervention (%)
Knowledge and Perception		
• Symptoms identification	94	100
• Causal agent	0	85.33
• Mode of transmission	29	98
Use of management methods		
• Sanitary measures	20	96
• Cultural practices	67	85.73
• Use of disease free & tolerant clones	32	94.33
• IDM	0	97
• Chemical control expectation	100	5.33
Enset clonal diversity increased by	…	26.92
Collabrative BW management	0	100
BW incidence	93	21.3
Newly introduced clones used	0	95
Farmers adopting IDM	5	89.33

CONCLUSION

This review demonstrated that bacterial wilt is widely distributed to the major enset and banana growing agro-ecological areas through affecting the livelihood of the community significantly. Hence, participatory based IDM through collective action approach is seen as a viable option for the successful and sustainable control of enset BW as it involves suitable control components and different partners along with farming communities. In addition, due attention should be given by different stakeholders to the following tasks for managing the disease below economic injury level and maximizing the level of consumption: (1) Proper training should be given to the growers about occurrence, dispersal, survival and management options of the disease to create awareness and minimize losses, (2) Enset bacterial wilt control system shall be well integrated to the national and/or regional integrated pest and disease management programs, (3) further investigation should be carried out to identify the bioactive chemicals (AI) responsible for antibacterial activity on the in vitro application, and (4) different resistant breeding research should be conducted to identify the appropriate resistant gene and to develop resistant clones as another management options.

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