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Assessment of bacterial wilt (*Xanthomonas campestris* pv. *musacearum*) of enset in Southern Ethiopia

Mekuria Wolde[1]*, Amare Ayalew[2] and Alemayehu Chala[3]

[1]Madawalabu University, School of Agriculture, Plant Science Course Team, P. O. Box 247, Bale Robe, Ethiopia.
[2]The Partnership for Aflatoxin Control in Africa (PACA), Department of Rural Economy and Agriculture (REA), P. O. Box 3243, Roosevelt Street, Addis Ababa, Ethiopia.
3Hawasa Collage of Agriculture, School of Plant Science, P. O. Box 5, Hawasa, Ethiopia.

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Enset (*Ensete ventricosum*) production and productivity is threatened by many biotic and abiotic factors among which bacterial wilt of enset (BWE), caused by *Xanthomonas campestris* pv. musacearum is one of the major factors. There were no reports on the intensity and distribution of bacterial wilt of enset in South Nation Nationalities and Peoples' Regional State (SNNPRS). Hence, the objective of this study was to determine the distribution and incidence of bacterial wilt of enset in relation to age, altitude and clonal variation in major enset growing districts of South Nation Nationalities and Peoples' Regional State (SNNPRS). Three major enset growing Zones namely Gurage, Hadiya and Sidama were included in the survey. In each Zone, three Districts were selected based on enset production status and altitudinal variation. The disease was detected in all agro ecologies and districts, but in varying extent. Bacterial wilt prevalence and incidence was highest in Hadiya and estimated at 42.22 and 5.56%, respectively, while both disease prevalence and incidence were the lowest (26.67 and 2.86%, respectively) in Sidama. At District level wilt prevalence varied from 6.67% at Aletachiko District to 76.67% at Lemo District. Bacterial wilt incidence also ranged from 0.74% at Aletachiko District to 10.31% at Lemo District. Wilt prevalence and incidence were at the highest (50% and 5.81%, respectively) in the altitude range of 2000-2500 masl. The disease varied according to the crop growth stage, with severe (4.75%) in Cycle 4 (an age greater than 4) and less severe (0.2%) at Cycle 1 (age of less than one year). Highest disease incidence and prevalence (30 and 6.65%) were noted with a plant age of 4-5 years. The disease was highly associated with administrative Zone, District, altitude, number of clones and spacing in a logistic regression model.

Key words: Bacterial wilt of enset, wilt incidence, wilt prevalence, South Nation Nationalities and Peoples' Regional State (SNNPRS), enset clones

INTRODUCTION

Enset [*Ensete ventricosum* (Welw.) Cheesman] is a staple food for over 15 million people in Ethiopia (Brandt et al., 1997). The plant is a drought tolerant and multi-purpose crop of which all parts are utilized for different

*Corresponding author. E-mail: hendawysaber@yahoo.com.

purposes. Enset production is largely for human food, fiber, animal forage, construction materials, medicine and for cultural practices (Tsehaye and Kebebew, 2006). The major foods obtained from enset are *kocho*, *bulla* and *amicho*. The energy yield of enset is by far higher than those of several cereals and also reported to be higher than potato, sweet potato and banana (Pijls et al., 1995). More than 20% of Ethiopia's population depends upon enset for human food, fibre, animal forage, construction materials and medicines (Azerefegne et al., 2009).

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 production. Diseases are collectively the most severe biological problem for enset production. Enset diseases are caused by several bacteria, fungi, viruses and nematodes. Among these, bacterial wilt of enset (BWE), caused by *Xanthomonas campestris* pv. *musacearum* (Xcm) is the most important constraint to enset production (Brandt et al., 1997).

Enset bacterial wilt was first reported by Yirgou and Bradbury (1968) in Ethiopia in 1968 and is currently found in all the enset growing regions and on wild enset plants (Brandt et al., 1997). The disease also attacks banana and other *Musa* spp (Viljoen, 2010). BWE is currently restricted to Africa (Fenta and Karamura, 2012). Bacterial wilt attacks enset at any stage of growth, including full maturity (Brandt et al., 1997). Once established in an area, the disease spreads rapidly and results in total yield loss (Welde-michael, 2008a). 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. 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., 2008b). Survival of the pathogen is mainly through infected plant debris and infected soil (Mwebaze et al., 2006). Handoro (2014) also reported that Xcm can survive in *Kocho* for more than 14 weeks.

Bacterial diseases of plants, once established, are difficult to control owing 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).

Bacterial wilt is a destructive disease in all enset growing areas of Ethiopia. However, the current status and distribution of the disease in Ethiopia is not well assessed. Furthermore, farmers mention that bacterial wilt is more severe at high altitudes (Brandt et al., 1997), but this has not been scientifically tested. Even though the pathogen attacks all stages of the plant (Brandt et al., 1997), the comparative importance at different stages is not determined yet. Enset is propagated by suckers or shoots rather than by seeds. Enset suckers are ready for transplanting into the permanent field from three to five years after propagation, depending on agro-ecological condition and locations. Farmers commonly grow the plant in 3 to 4 cycles (growth stages) with 2-3 transplanting (for every year or two) in different field in a crop's life time by increasing spacing in each cycle or stage. Research to determine the incidence of the disease at these stages would generate information that would contribute towards targeted management of the disease. Hence, this study was proposed with objectives of, determining the distribution and incidence of bacterial wilt of enset in relation to age, altitude and clonal variation in major enset growing districts of South Nation Nationalities and Peoples' Regional State (SNNPRS).

MATERIALS AND METHODS

Sampling procedures

To determine the incidence and distribution of bacterial wilt of enset in major enset growing areas of SNNPRS, particularly to assess the situation after the recent upsurge of the disease, a reconnaissance survey was made from enset growing farmers' fields. Three administrative Zones, namely Gurage, Sidama and Hadiya were covered in the study (Figure 1). They were selected purposively by their potential enset production. Districts were stratified into three agro-ecological groups, based on altitudinal range and one District was selected in each agro-ecology. For the ease of this research work ago-ecologies were categorized into three altitudinal ranges (groups), namely less than 2000 masl, 2000-2500 masl and greater than 2500 masl. In each District three representative kebeles were selected and ten enset farms were assessed at a distance of fixed interval from one to two kilometers from each kebele based on enset availability. Thus, a total of 270 enset fields were assessed in the survey.

Disease assessment

The status of BWE at each field was assessed and recorded through direct field observations. In each enset field, the plants were classified into three to four stages based on the crop age (growth stages) and cropping systems used by the farmers. Based on these, stage one is less than one year old sucker developed from a single corm, stage two is two years old which are transplanted from stage one, stage three is three to four years old and stage four is four years to harvesting (maturity) stage in which all are grown in separate field and different spacing. Based on the stages, random sampling was made for row selection. Within the row, two consecutive plants were assessed at an interval of five successive plants. In each stage, the total number of plants and the number of plants showing typical bacterial wilt symptoms were recorded. Disease incidence for each stage was calculated as

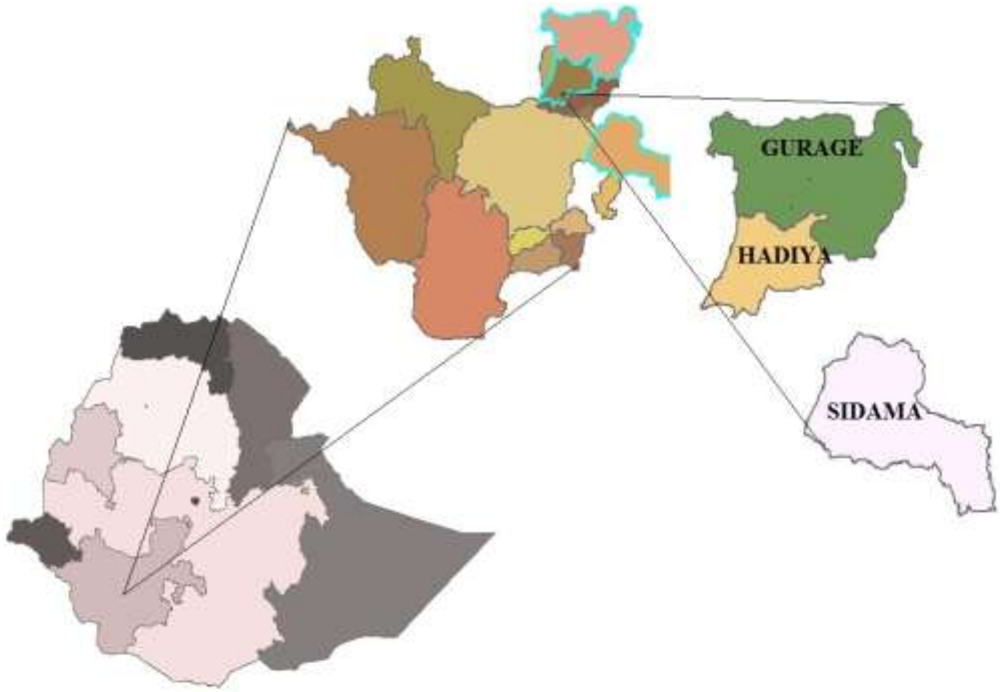

Figure 1. Map of Ethiopia showing locations of SNNPRS and Zones surveyed for BWE disease.

number of plants showing wilting symptom divided by total number of plants assessed multiplied by 100. Average wilt incidence for the field was obtained by summing up the percentage wilt incidence for each stage divided by three or four (based on the number of stages used). Prevalence of the disease was calculated using percentage of fields encountered with bacterial wilt disease.

Prevalence = (NWF/NTF) × 100

Where, NWF = the number of fields with bacterial wilt symptom and NTF = the total number of fields.

Wilt Incidence = (NWP/TNP) × 100

Where, NWF = the number of plants infected by bacterial wilt symptom and NTF = the total number of plants assessed.
In addition to bacterial wilt incidence, supplementary information was also recorded through direct field observation, interview with enset growers and global positioning system (GPS).

Data analysis

Simple descriptive statistics were used to summarize data obtained from field surveys after being entered in SPSS computer program version 20.0 for Windows. Summary of wilt incidence was presented for each independent variable and variable classes. The association of BWE incidence and incidence at Cycle 4 with independent variables were analyzed using logistic regression as described by Yuen et al. (1996) and Hosmer and Lemeshow (1989) with the SAS Procedure GENMOD (SAS for Windows, 2002-2003, SAS Institute). The wilt incidence and wilt incidence at Cycle 4 were classified into distinct groups of binomial qualitative data. Thus, ≤15 and >15% were chosen for wilt incidence yielding a binary dependant variable. Class boundaries of ≤20 and >20% were chosen for incidence at Cycle 4.

The logistic regression model allows evaluating the importance of multiple independent variables that affect the response variable (Yuen et al., 1996). The GENMOD (generalized linear models) Procedure gives parameter estimates and the standard error of the parameter estimates. Exponentiating the parameter estimate yields the odds ratio, which is interpreted here as the relative risk (Yuen et al., 1996). The importance of the independent variables was evaluated in two ways. First, the association of an independent variable alone with BWE incidence or wilt incidence was examined. In the other method, independent variables with high association to both parameters were added to reduce multiple variable models. The odds ratio shows the strength of association between a predictor and the response of interest.

RESULTS AND DISCUSION

Prevalence of BWE

From 270 enset fields assessed in the three Zones, on average 34.81% enset of the fields were affected by the disease. However, Africa RISING (2014) reported that 80% of enset farms during the 2013 growing season were infected with BWE. During the survey period, it was recognized that the disease was widely distributed and detected in all agro-ecologies and locations. This was in agreement with reports by Ashagari (1985); Anita et al. (1996) and Spring et al. (1996). The disease was most prevalent in Hadiya Zone with 42.22% BWE prevalence, while only 26.67% and 35.56% of enset fields were affected by the disease in Sidama and Gurage Zones, respectively. On the contrary, Brandt et al. (1997) reported that higher wilt prevalence was occurred in

Table 1. Mean incidence and prevalence of BWE for different production locations in SNNPRS.

Variables	Variable class	NIF	Prevalence (%)	Incidence (%)				
				Max.	Min.	Mean	SD.	SEM.
Total		94	34.81	28.57	0.00	3.89	6.15	0.37
	Gurage	32	35.56	16.67	0.00	3.21	4.93	0.52
Zones	Hadiya	38	42.22	28.57	0.00	5.56	7.44	0.78
	Sidama	24	26.67	22.22	0.00	2. 89	5.49	0.58
	<2000	15	16.67	17.24	0.00	1.91	4.37	0.46
Altitude (masl)	2000-2500	45	50	28.57	0.00	5.81	7.27	0.77
	≥2500	33	36.67	20.00	0.00	3.93	5.87	0.62
	Edja	14	46.67	16.67	0.00	4.10	5.57	1.02
	Cheha	6	20	10.34	0.00	1.52	3.17	0.58
	Gumer	12	40	15.79	0.00	4.00	5.39	0.98
District	Aletachiko	2	6.67	11.43	0.00	0.74	2.81	0.51
	Wonsho	9	30	22.22	0.00	3.05	5.67	1.03
	Lemo	23	76.67	28.57	0.00	10.31	8.21	1.49
	Hula	13	43.33	20.00	0.00	4.86	6.61	1.20
	Misha	7	23.33	16.3	0.00	2.93	5.56	1.02
	Gibe	8	26.67	17.24	0.00	3.46	6.05	1.10

SD, Standard Deviation; SEM, Error mean square; NIF, Number of infected fields; Max., maximum; Min, minimum.

Gurage Zone, followed by Hadiya, while similar report was for Sidama Zone. Similarly, Anita et al. (1996) also reported the disease was devastating in these areas during 2013 growing season.

There was variation in BWE prevalence across altitudes with the disease being most prevalent (50%) in at an altitude of 2000-2500 masl. This was followed by >2500 and <2000 masl, which had BWE prevalence averaging on 36.67% and 16.67%, respectively (Table 1). Brandt et al. (1997) found out that the disease was more severe in highlands than in lowlands. A study by Maina et al. (2006) also reported that the disease is severe at midland in banana plant. When comparisons were made across seasons, some farmers responded that the disease is more severe in summer than in winter. This indicates the pathogen may require high moisture and lower temperature. There was slight variation in BWE prevalence, when comparisons were made between cropping practices. About 30.58% of intercropped fields were affected by the disease and 36.93% of monocropped fields were infected with the disease, which was statistically insignificant.

At the District level, the highest BWE prevalence (76.7%) was registered in Lemo District (Hadiya Zone). It was followed by Hula, Edja, Gumer and Wonsho Districts with 43.33, 46.67, 40 and 30% disease prevalence, respectively. Aletachiko, Cheha, Misha and Gibe Districts were less affected by the disease, with 6.67, 20, 23.33 and 26.67% BWE prevalence were registered, respectively.

Even though bacterial wilt could infect enset at all cycles and growth stages, minimum disease prevalence occurred in Cycle 1 where only 1.11% of the surveyed fields were affected by the disease. Likewise, 20% of Cycle 2, 20.56% of Cycle 3 and 31.48% of Cycle 4 enset fields were affected by BWE disease. Disease data for Cycle 4 was categorized into two age groups, with an age of four to five years and age greater than or equal to six years for analysis. Hence, higher (30%) disease prevalence was recorded at age of four to five and less (14.07%) in an age greater than or equal to six (Table 2). The present finding is in agreement with the findings of Brandt et al. (1997) where the disease was severe at middle age. However, Welde-michael et al. (2008a) indicated in an experiment involving cutting of plants with contaminated knife that older plants were less vulnerable to infection than young plants. On the other hand, higher disease prevalence (36.89%) was recorded on fields with fewer than or equal to five clones diversity per enset fields. Similarly, 33.53% of enset fields containing more than five clones were affected by the disease. However, during the survey period some farmers, which have the disease in their farm, grew only few clones, in which they believed that these clones are resistant to the disease.

Nearly similar wilt prevalence was recorded for spacing greater than 1.5*1.5 m and less than or equal to 1.5*1.5 m, with 32.9 and 37.2% of enset fields respectively, being affected by the disease. Correspondingly, 30.3% and 33.1% wilt prevalence was registered in Cycle 4. On the other hand, spacing data for Cycle 3 were grouped in to

Table 2. The mean incidence and prevalence of BWE for different variables.

Variables	Variable class	NIF	Prevalence (%)	Incidence (%)				
				Max.	Min.	Mean	SD.	SEM.
Cropping Cycle	Cycle 1	3	1.11	20.0	0.00	0.20	1.87	0.11
	Cycle 2	54	20	40.00	0.00	2.48	6.95	0.42
	Cycle3	37	20.56	40.00	0.00	4.13	8.93	0.67
	Cycle 4	85	31.48	37.50	0.00	4.75	7.92	0.48
Age (year)	4-5	81	30	57.14	0.00	6.55	11.32	0.69
	≥6	38	14.07	33.33	0.00	2.37	6.25	0.38
Cropping Sys	Intercrop	29	30.85	21.62	0.00	3.61	6.01	0.62
	Mono crop	65	36.93	28.57	0.00	4.04	6.23	0.47
Spacing at C4 (m)[a]	>1.5*1.5	50 (43)	32.9 (30.3)	21.62 (23.81)	0.00 (0.0)	3.39 (4.30)	5.46 (7.17)	0.44 (0.58)
	≤1.5*1.5	44 (41)	37.2 (33.1)	28.57 (37.5)	0.00 (0.0)	4.53 (5.33)	6.9 (8.79)	0.63 (0.81)
Spacing at C3 (m)[c]	≥1*1	18	19.35	33.33	0.00	3.70	8.16	0.85
	<1*1	19	21.87	40	0.00	4.58	9.71	1.04
Enset FS (ha) Priority of Enset	>0.25	43	30.71	25.81	0.00	3.22	5.72	0.48
	≤0.25	51	39.23	28.57	0.00	4.60	6.52	0.57
	1st	80	32. 92	28.57	0.00	3.66	6.02	0.38
	2nd	12	54.54	22.86	0.00	6.45	7.36	1.57
	3rd	2	40	10.71	0.00	3.62	5.09	2.28
No. of clone	≤5	38	36.89	22.2	0.00	4.19	6.22	0.61
	>5	56	33.53	28.57	0.00	3.70	6.11	0.47

[a] data in parenthesis are for Cycle 4 only; [c] data for only Cycle 3; SD, Standard Deviation; SEM, Error mean square; NIF, Number of infected fields; Max., maximum; Min, minimum.

two, ≥1*1 m and less than 1*1m. Based on this, about 19.35% of enset fields at Cycle 3 cultivated in wide spacing (≥1*1 m) were infected with the disease, while 21.87% of enset fields at Cycle 3 with a spacing of less than 1*1 m were infected with BWE. This indicated that close spacing increase the disease prevalence at both cycles.

Incidence of BWE

The mean incidence of BWE varied for different variables and variable classes (Tables 1 and 2). The overall mean incidence of the disease during the survey time was 3.89%. Mean BWE incidence varied from 2.89% in Sidama Zone to 5.56% in Hadiya Zone. Mean incidence of the disease in Gurage Zone was 3.21%. The high BWE

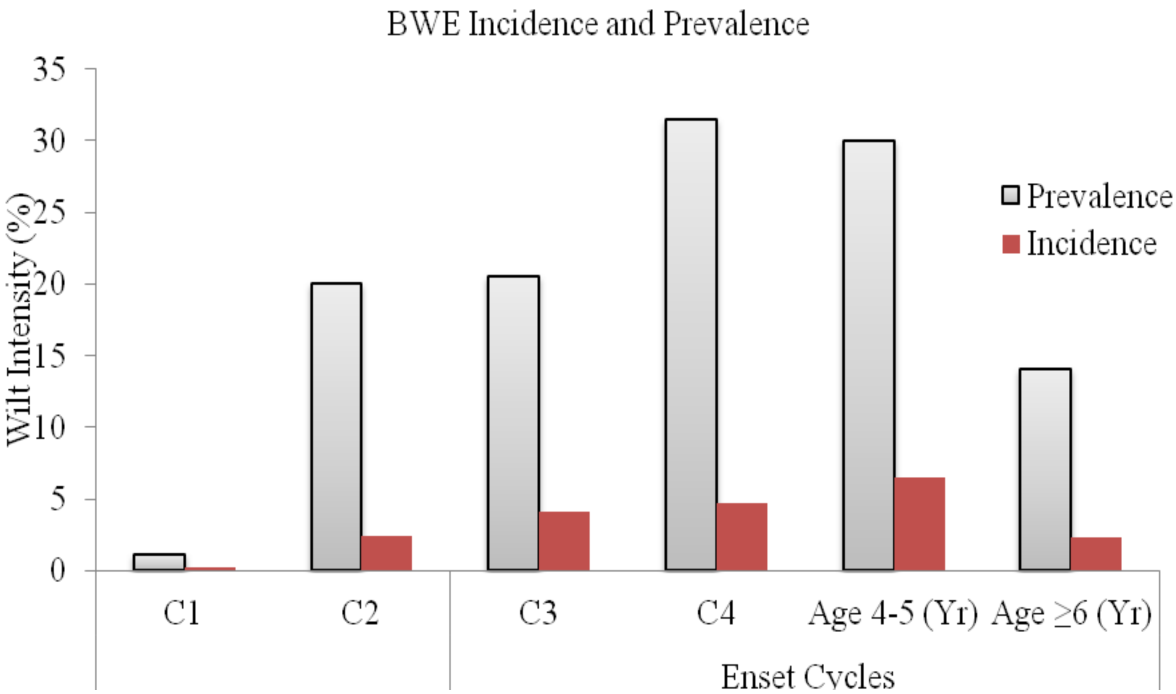

Figure 2. Mean BWE prevalence and incidence at different cycles and ages of enset in SNNPRS. C1 = Cycle 1; C2 = Cycle 2; C3 = Cycle 3 and C4 = Cycle 4.

incidence in Hadiya Zone might be attributed to management practices, environmental factors and awareness of the farmer for transmission and management. A maximum mean incidence of 5.81% was recorded in the altitude of 2000-2500 masl, while minimum mean incidence of 1.91% was recorded in an altitude of less than 2000 masl, and the BWE mean incidence in high altitude (>2500 masl) was intermediate and was estimated at 3.93%.

Among the enset fields surveyed in nine Districts, the least mean incidence (0.74%) was recorded in Aletachiko District, followed by Cheha and Misha District with mean incidence of 1.5 and 2.93%, respectively. Likewise, the highest mean incidence (10.31%) was recorded in Lemo District, followed by Hula and Edja Districts with mean incidence of 4.86 and 4.10%, respectively. During the survey, Lemo District was found as the most affected area. Africa RISING (2014) has also reported high infestation at Lemo District. The farmers in Lemo District responded that the disease was lower at winter (dry) time and they grew enset continuously without rotation, since the disease is soilborne and it was severely affected, rotation with other crop might be better for this area. The other reason for high incidence of the disease at Lemo may be due to the virulence of the pathogen. Haile et al. (2014) reported there is a huge variation for Xcm isolates in their pathogenicity.

Minimum mean BWE incidence (0.20%) was recorded in Cycle 1, followed by Cycle 2 with 2.48% mean incidence. Maximum mean incidence (4.75%) was registered in Cycle 4, while BWE mean incidence at Cycle 3 was 4.13% (Figure 2). This indicates that the disease was more destructive in Cycles 3 and 4 and less destructive in Cycles 1 and 2. But it does not indicate that at younger age of the plant it is immune to the disease. However, this might indicate that suckers had no or little significant role in the transmission of the disease, but they might cause latent infection. The highest wilt incidence at middle age might be due to long exposure time of the host to the pathogen and crop management practices. Moreover, higher cycles are more prone to frequent cut by infected farm tools for different purposes. In this connection, BWE incidence was higher at an age of 4 to 5 years with mean incidence of 6.55% and minimum (2.37%) at an age of greater than 5 years in Cycle 4 during the survey time (Figure 2). This indicates that wilt incidence was higher at mid stage than at juvenile or sucker stage. However, Hayward (2006) reported that suckers are an important means of spread for systemic bacterial diseases. On the other hand, farming instruments may play great role in disease transmission during transplanting and other management practices.

BWE incidence was greater in monocropping than in intercropping with mean incidence of 4.04 and 3.61%, respectively. But it was not significantly different from each other. Bacterial wilt incidence at whole field was at maximum in narrower spacing (less than or equal to

Table 3. Independent variables used in logistic regression modeling of BWE incidence and incidence at Cycle 4 and likelihood ratio test for 6 variables.

Independent variable	DF	Wilt incidence LRT >15%		Incidence at Cycle 4 LRT >20%	
		Deviance	Pr > x^2	Deviance	Pr > x^2
Zone	2	2791.91	<0.0001	3625.00	<0.0001
District	8	2417.09	<0.0001	3133.77	<0.0001
Altitude	2	2687.62	<0.0001	3450.02	<0.0001
Cropping system	1	2405.32	0.1765	3091.89	0.50
Number of clone	1	2344.15	<0.0001	3056.68	<0.0001
Spacing at Cycle 4	1	2324.45	<0.0001	3046.37	0.0013

DF, degrees of freedom; Pr, Probability of a x^2-value exceeding the deviance; LRT, likelihood ratio test.

1.5*1.5 m) than in wider spacing (greater than 1.5*1.5 m) with an incidence of 4.53 and 3.39%, respectively. Likewise, the mean incidence in Cycle 4 with narrow (less than or equal to 1.5*1.5 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 (greater than 1.5*1.5 m) enset fields (Table 2). This might be attributed to higher disease transmission in narrow spacing, because of suffocation, humid microclimate and physical contact, which aggravate disease spread. That is why it had strong influence on wilt incidence and little influence on wilt prevalence. Similarly, spacing at Cycle 3 had influence on wilt incidence. Maximum wilt incidence (4.58%) was recorded in narrow spacing (less than 1*1 m), while 3.58% wilt incidence was recorded in enset farms with spacing greater than or equal to 1*1 m at Cycle 3.

Data on the field size were grouped into two ranges (≤0.25 and >0.25 ha). Incidence of 4.60% were recorded in enset field size of less than or equal to 0.25 ha and 3.22% incidence was noted in enset farm size with greater than 0.25 ha. It appeared that the field size and cropping system had an influence on BWE incidence. To this effect, maximum wilt incidence (5.73%) was recorded in enset farms where less than 30 ensets per year were harvested, followed by farms where 31-49 ensets were harvested per year with correspondingly 3.88% incidence, while minimum wilt incidence (1.28%) was recorded in enset farm fields where greater than 49 ensets were harvest per year. Higher wilt incidence (4.19%) was registered from enset fields which posses less than or equal to five clones per enset field, while lower (3.70%) incidence was from diversified enset fields.

Association of bacterial wilt of enset with independent variables

Enset bacterial wilt incidence and wilt incidence at Cycle 4 were significantly associated with most of the independent variables in the logistic regression (Table 3). Both disease parameters were significantly associated (p<0.0001) with five variables, namely, administrative Zone, District, altitude range, number of enset clones and plant spacing at Cycle 4. However, both BWE incidence and incidence at Cycle 4 have no significant association (p<0.0001) only with enset farming system. The likelihood ratio test showed that the associations of the administrative Zone, altitude and District with infection of BWE were the highest as evidenced by higher deviance reductions and $x2$ value.

The variables that showed significant associations in likelihood ratio test were tested in reduced multiple variable models with wilt incidence and incidence at Cycle 4 as a dependent variable. Low wilt incidence (≤15%) had a high probability of association to Aletachiko, Cheha and Gibe District, to lower altitude (<2000 masl) and wider planting space at Cycle 4 (>1.5*1.5 m) (Table 4). Similarly, Aletachiko, Cheha and Gibe District, to lower altitude (<2000 masl) and narrow spacing had a high probability of association to lower wilt incidence (≤20%) at Cycle 4.

On the other hand, high wilt incidence (>15%) had a high probability of association to Gurage Zone, Lemo, Edja and Hula Districts, mid altitude (2000-2500 masl) and diversified enset fields (>5 clones). Likewise, high incidence (>20%) in Cycle 4 had high probability of association to Hadiya Zone, Lemo District, altitude of 2000-2500 masl and less diversified fields (≤5 clones per enset farm). There were about four times greater probabilities that wilt incidence would exceed 15% in the Lemo District as compared to Wonsho District. Similarly, the probability of occurrence of high wilt incidence in an altitude of 2000-2500 masl and less number of clones was about four and two times greater than in altitude of <2000 masl and more diversified enset fields, respectively. On the other hand, the probability of occurrence of high wilt incidence (>20%) at Cycle 4 in Lemo District and at altitude range of 2000-2500 masl was about five and four times greater as compared to Wonsho District and at an altitude of <2000 msal, respectively.

There were about seven and two times less probabilities that wilt incidence would exceed 15% in

Table 4. Analysis of deviance, natural logarithms of odds ratio, parameter estimate and standard error of added variables in logistic regression model analyzing BWE incidence and incidence at Cycle 4.

			Wilt incidence			Incidence at Cycle 4		
Variable	**DF**	**Variable class**	**Parameter estimate**	**SE**	**Odds ratios**	**Parameter estimate**	**SE**	**Odds ratios**
Intercept			-1.94	0.15	0.14	-1.94	0.13	0.14
Administrative Zone	2	Gurage	0.26	0.17	1.3	0.008	0.15	1.08
		Hadiya	0.09	0.17	1.09	0.062	0.14	1.06
		Sidama	0.00[a]	0.00[a]	1	0.00[a]	0.00[a]	1
District	8	Aletachiko	-1.91	0.25	0.15	-1.64	0.20	0.19
		Cheha	-0.82	0.19	0.44	-0.95	0.17	0.39
		Edja	0.40	0.15	1.49	0.21	0.14	1.2
		Gibe	-0.24	0.16	0.79	-0.52	0.15	0.59
		Gumer	0.26	0.17	1.3	0.008	0.15	1.01
		Hula	0. 40	0.15	1.49	0.31	0.13	1.36
		Lemo	1.45	0.13	4.26	1.53	0.12	4.62
		Misha	0.09	0.16	1.09	0.06	0.14	1.06
		Wonsho	0.00[a]	0.00[a]	1	0.00[a]	0.00[a]	1
Altitude (masl)	2	<2000	-0.33	0.17	0.72	-0.58	0.16	0.56
		2000-2500	1.45	0.14	4.26	1.46	0.12	4.31
		≥2500	0.00[a]	0.00[a]	1	0.00[a]	0.00[a]	1
Number of clones	1	≤5	0.49	0.09	1.63	0.46	0.08	1.58
		>5	0.00[a]	0.00[a]	1	0.00[a]	0.00[a]	1
Spacing at Cycle 4 (m)	1	>1.5*1.5	-0.31	0.07	0.73	-0.20	0.06	0.82
		≤1.5*1.5	0.00[a]	0.00[a]	1	0.00[a]	0.00[a]	1

[a] Reference group; DF, degrees of freedom; Pr, Probability of a x^2-value exceeding the deviance; SE, standard error.

Aletachiko and Cheha Districts as compared to Wonsho District, respectively. However, there were five, three and two times lesser probabilities that wilt incidence at Cycle 4 would exceed 20% in Aletachiko, Cheha and Gibe Districts as compared to Wonsho, respectively. Similarly, the probability of occurrence of high wilt incidence at Cycle 4 in an altitude of <2000 masl was about two times lesser as compared to 2000-2500 masl area (Table 4).

Thus, the incidence of BWE and incidence at Cycle 4 appeared to be influenced by different independent variables. The association of wilt incidence to altitude could be attributed to the preferences of the pathogen for moisture and temperature requirement or might be for the difference in production system in different agro-ecologies. Ashagari (1985) and Maina et al. (2006)

also reported that the pathogen requires humid condition for survival. A similar report by Smith et al. (2008) indicated that altitude and environmental factor as the two major factors influencing the pathogen. Similarly, the association of BWE incidence with enset growing areas (administrative Zone and District) could be attributed to enset production and management system, type of clone grown and environmental effect. The association of wilt incidence and incidence at Cycle 4 to spacing might be related to pathogen transfer in contact with healthy plant in close or narrow spacing. On the other hand, the association of number of clones to both disease parameters could be, the farmers grow only some clones which tolerate the disease on their farm.

CONCLUSION AND RECOMMENDATIONS

Bacterial wilt of enset is one of the major biotic constraints of enset production in major enset producing parts of Ethiopia and it is widely distributed in all enset producing areas. It can result in up to 100% yield loss when causing complete wilting. The field survey in three major enset growing Zones, namely Gurage, Hadiya and Sidama of SNNPRS revealed the wide distribution of BWE although at varying intensity. It was noted during the survey that the disease has been reducing the yield by about 3.9% of enset in the survey area.

The average prevalence and incidence of the disease across the survey areas in the three Zones were 34.81 and 3.89%, respectively. The disease was more destructive in four Districts, namely Lemo (Hadiya), Edja (Gurage), Hula (Sidama) and Gumer (Gurage). Aletachiko and Cheha Districts were the least affected Districts by BWE. 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. Variation in BWE was also observed due to growth stages. The disease was severe at Cycle 4 and at an age of 4 - 5 years and lowest at Cycle 1. However, the pathogen could attack the plant at any growth stage. In the survey areas, the farmers depended on enset for their food security. Besides, the disease has been threatening their economy and food security. The disease has also been risking the genetic diversity of the plant. The traditional cultivation practices, like cutting during propagation and agronomic practices of enset contributed to infection and spread of the disease.

Understanding disease epidemiology as affected by different variables is useful to design sustainable BWE management strategies. The present study identified that the disease was influenced by agro-ecology, plant population, growth stage and type and number of clones in enset fields. The result of this study confirmed that including these variables in developing management strategies for the disease is essential. The disease was most severe at Cycle 4, which was mostly prone to contamination by cutting with infected instruments. Therefore, reducing the enset cutting frequencies when the disease is suspected to prevail is important. Close spacing of enset had influence on increasing the disease spread, so wider spacing of greater than 1.5*1.5 m is recommended for reducing the disease spread.

Awareness creation among the farmers about the disease transmission, waste disposal methods and management options is essential. The present one season study is not complete in terms of sample size and area coverage. However, enset is important crop in other areas as a major food crop and the disease is devastating in such locations. Therefore, the status and distribution of the disease should be further determined. The effect of the disease at different growing seasons should also be assessed.

Conflict of Interests

The authors have not declared any conflict of interests.

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