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Community based integrated enset bacterial wilt (*Xanthomonas Campestris pv. musacearum*) management through collective actions in central Ethiopia region

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ABSTRACT: **Enset *ventricosum* (Welw.) Cheesman is an important food crop produced in southern part of Ethiopia and plays an important role in food security. However, the production of the crop is declines due to enset bacterial wilt disease caused by *Xanthomonas campestris*. Hence, the present study was designed with the aim of determining the epidemiology of bacterial wilt with the demonstration and dissemination of integrated disease management options in Mirab Azernet and Cheha district of central Ethiopia during the 2019-2021 growing season. Epidemiological information collected was using semi-structured designed questioners before and after intervention of integrated BW management. Natural epidemics of the disease showed a wide range of disease incidence at different plant growth stages. Based on a base line assessment, the average prevalence and incidence of three Kebele in Cheha district were estimated to be 65.7% and 48.1% respectively, while the average prevalence and incidence of three selected Kebele in Mirab Athernet were 52.8 and 36.9%, respectively. After intervention, the average prevalence of the disease was reduced to 5.6% in Mirab Azernet and to 10.1% in Cheha district. Sanitary control measures demonstrated the promising result in BW reduction. However, this traditional method of disease management option has not always the sustainable solution to alleviate the disease. To achieve a successful and sustainable bacterial wilt control measure, implementing IDM in enset farming community is the advisable approach to tackle the food insecurity of enset growers.**

KEYWORDS: Enset, Bacterial wilt, Incidence, Prevalence, Severity

INTRODUCTION

Enset (*Ensete ventricosum* (Welw.) *Cheesman*) is an indigenous perennial crop in Ethiopia that belongs to the family Musaceae and the genus Ensete. In Ethiopia, crops play an important role in the daily lives of our farmers and are grown as a staple food. The crop is versatile and environmentally resilient, and more than 20 million Ethiopians rely on it as a staple and co-staple food source, fiber, animal forage, construction materials, and medicine [1]. The plant can withstand long periods of drought, heavy rains, and flooding, and it is a multipurpose crop, with all parts used for various purposes. Enset provides Kocho and Bulla, which are obtained from pseudo stem and leaf petioles, and Amicho is the other product obtained from the underground corm that is eaten boiled [2, 3]. The crop is also important in terms of influencing soil erosion and sediment yield via its root fiber systems, which facilitate infiltration, hold soil in place, and reduce soil erosion severity [4]. Because of these characteristics, the crop is better suited to sustainable agricultural systems, contributing soil fertility, long storability, multiple uses, and accessibility at any time, and relatively high productivity depending on edaphic factors, altitude, cultural practices, and varietal differences [5, 6].

Despite its importance to our environment in terms of soil and water conservation and as a food security crop, production is influenced by a variety of factors, including biotic and abiotic agents such as diseases, insect pests, weeds, wild animals, and soil nutrient depletion, all of which contribute to low yield and poor quality enset production. In Ethiopia, various diseases and insect pests of enset have been reported. Enset is susceptible to a variety of diseases caused by bacteria, fungi, viruses, and nematodes, which are major production constraints [7]. Enset diseases are caused by various bacteria, fungi, viruses, and nematodes. Among these, bacterial wilt (BW), caused by *Xanthomonas campestris* pv. *musacearum* (Xcm), is the most significant bottleneck in enset production. According to research reports, EBW disease causes losses of up to 100% in some enset fields [8], resulting in significant economic loss in the country's major enset growing areas. Enset bacterial wilt was found to cause yield losses of up to 100% [9]. The tradition of sharing planting materials in enset farming communities is thought to have played a significant role in the disease's spread across growing areas in the country. As a result, disease management and control have become increasingly difficult.

Various management strategies are being implemented to combat the EBW epidemic in various enset growing area of our countries. To reduce disease risk, farmers grow enset clones that are relatively resistant/tolerant. Farmers also uproot and discard infected enset from their fields; cultural practices such as tillage and spacing, crop rotation, and manure are other options used by most enset growers. Other practices include disinfection/flaming of enset cutting tools after use on infected plants, preventing animals from browsing infected plants, fencing infected sites, and thorough removal of infected plants (including corms) [10]. According to Handoro et al. [11], the most effective control measures are cultural practices and sanitation (such as the removal of infected plants and plant parts). However many farmers do not use the appropriate and recommended practice to manage the disease. Farmers also have no enough perception about the effectiveness of integrated disease management of EBW.

Siltie and Gurage zones are among the major enset growing areas of central Ethiopia. The large numbers of enset clones are growing in a wide range of altitude at both zones. The community of the areas is mainly depends on enset for their food and income source. However, bacterial wilt is the primary challenge of enset grower in the areas. Continuous monocropping of enset crops for an extended period of time in one area contributed to disease spread. Farmers in the area also lack precise knowledge of improved EBW disease management strategies. Because of these and other reasons, it is important to study the epidemiology of the disease by demonstrating the integrated disease management (IDM) methods of bacterial wilt and identifying gaps to considered in the future research directions.

MATERIAL AND METHODS

Description of the study area

The study was carried out during the 2019-2021 cropping seasons in the Merab Athernet and Cheha districts. The areas were chosen specifically based on enset production potential and bacterial wilt disease distribution. Initially, Kebeles (peasant associations (PA's) were selected in collaboration with the zonal and district agricultural offices. Three Kebele were selected from each district for demonstration of EBW management. These were namely Kecha chumeto, Bilalo and Duna from Mirab Azerenat while Yeferezye, Yewozhia and Girar from Cheha district. Merab Azernet Berbere is one of the potential enset producing district of Siltie zone. The district is situated under major enset growing areas of central Ethiopia region characterized by highland agro ecologies. Mirab Azernet is situated at 07^{o}84′65″N, 38^{o}18′18″ E (Figure 1) in the Siltie zone, located 252 kilometers southwest of Addis Ababa. The altitudinal range of surveyed peasant associations (PA's) in the district ranged from 2354-2794 m.a.s.l. The annual rainfall in the area ranges from 1030 to 1380mm, indicating highland agro ecology. The average annual minimum and maximum temperatures are 8.05°C and 18.9°C, respectively. The soil type is dominated by Clay soil (Chromic Luvisols and Haplic phaeozems) which is slightly acidic. Cheha is the other district located at 07^{o}84′65″N, 38^{o}18′18″E (Figure 1) in the Gurage zone, 255 kilometers southwest of Addis Abeba. Topographically, the selected

Kebeles in the district are located at elevations ranging from 2115 to 2636 meters above sea level. The annual rainfall ranges between 620 and 1290 mm, representing midland and highland agroecology. The average annual minimum and maximum temperatures are 7.6°C and 27.6°C, respectively. The soil type is dominated by clay soil (Chromic Luvisols) and pellic vertisols. Both locations experience bimodal rainfall, with a short rainy season from March to May and a main rainy season from June to September.

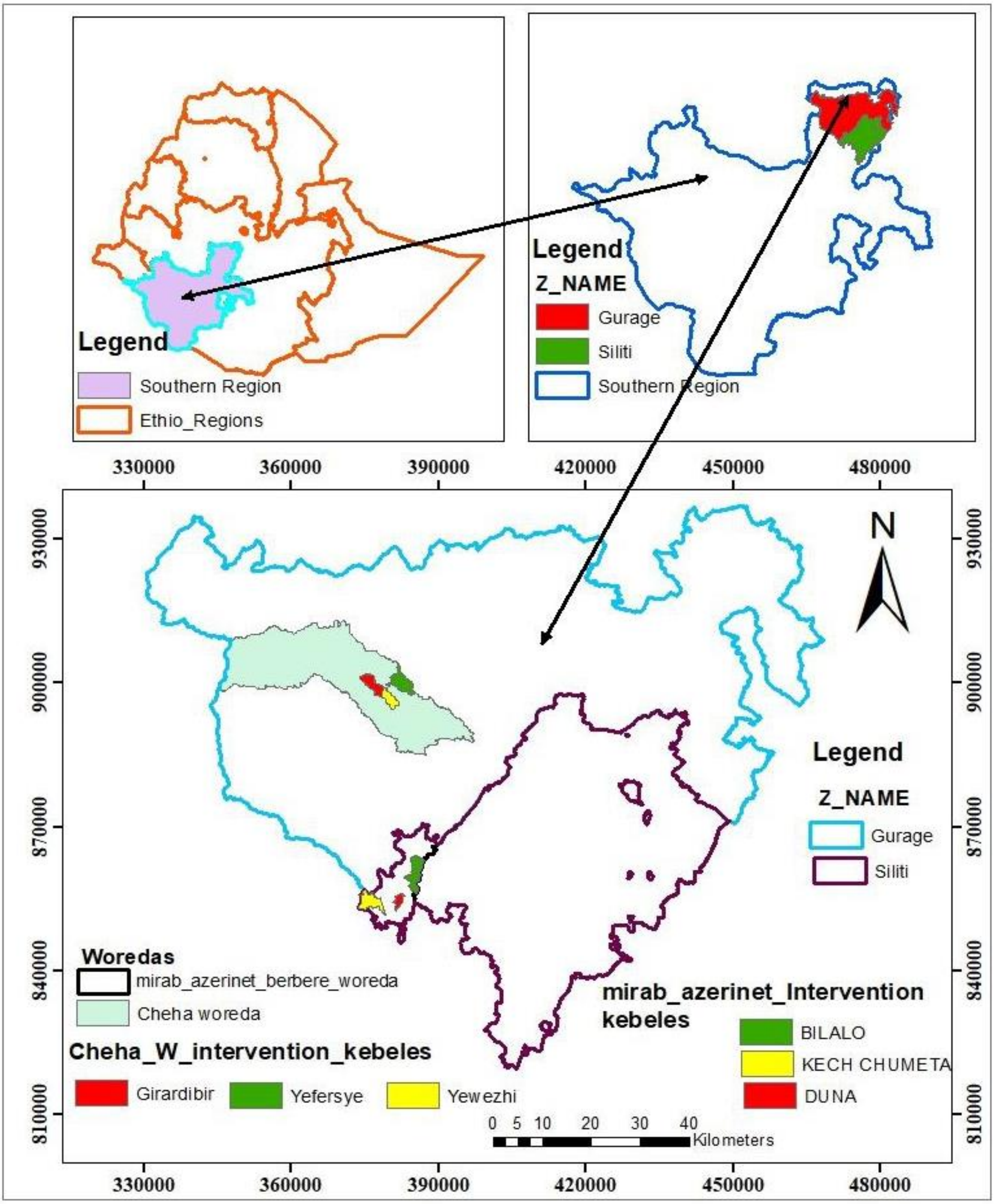

Figure 1. Map showing study areas

Intervention step approach

Field survey

Individual interviews, as well as direct on-farm participation, were used to collect data. Data were gathered using semi-structured designed questioners based on farmer indigenous knowledge. During the baseline survey, 75 farmers from each district were interviewed about host pathogen interaction, as well as information about the study area, landholdings, crops commonly grown, and specific information on enset production challenges.

Awareness creation and training

To better understand the scientific approach to managing EBW, the farming community was sensitized, awareness was raised, and training was provided. A total of 163 stockholders received theoretical and practical training, including district and Kebele administrators, district agricultural office heads, Development agents (DAs), horticultural and extension service experts, religious, Idir, and Iqub leaders, respected local elders and elites, model farmers, school principals, women, and youth affairs. Various topics were covered during the training for participants, such as enset production, field management, the cause of enset bacterial wilt, disease symptoms, disease transmission, and disease control mechanisms.

Discussion

Following training, discussions were held with the respective stack holders and relevant partners in both districts about the study's objectives, participation, mass mobilization, and logistics for the collective action. During the discussion and negotiation, the actors established by-laws titled "Integrated Enset Bacterial Wilt Management" to guide community members in managing enset bacterial wilt. Task forces were formed, and farmers set a date to rough out and bury the infected enset using mass mobilization. Werabe Agricultural Research Centre provided continuous monitoring and evaluation during the eradication and removal of infected ensets. During the study, interviews and field observations were conducted in the areas to document the indigenous knowledge associated.

Data collected

During the baseline survey, data on the host-pathogen relationship were collected, including the names of clones, the number of infected enset clones, the purpose for which each clone was grown, the reaction of each clone to the pathogen (EBW), farmers' perceptions of the causes and modes of disease transmission, disease management strategies, and farmers' indigenous knowledge of symptom identification. End-line survey was conducted during the rainy season from August to September 2021, and typical symptoms of enset bacterial wilt were clearly expressed by farmers in both districts. Following intervention, all information gathered during the baseline survey was collected during the end-line survey for comparison with the two survey results. End-line surveys were collected from farmers who were trained about enset bacterial wilt, as well as those who were untrained. Data from 75 household from each districts were collected and 25 target households were selected from each PA’s and involved in EBW disease data collection. Data on incidence and prevalence of enset bacterial wilt in the entire PA’s were recorded pre and post implementation of collective action for eradication.

Incidence = (NW/NT)×100,

where, NT is the number of total tested plants and NW is the number of wilted plants.

Diseases prevalence was expressed in percentage and measured by dividing the number of fields affected to the total number of fields assessed.

$$\text{Prevalence }(\%) = \left(\frac{\text{No of fields affected}}{\text{Total fields assessed}}\right) * 100$$

Data analysis

Data was analysed in a simple descriptive tabular format and Arc GIS version 10.5.1 computer software programs used to compute map of the surveyed areas.

RESULT AND DISCUSSION

Enset bacterial wilt has had a significant impact on the socioeconomic development of rural communities in the studied areas. The majority of livelihoods suffered significantly as a result of the bacterial wilt disease. During the baseline survey, the majority of interviewed heads of households (81.9%) were men. On the other hand, during the end-line survey, approximately 76.5% of the interviewed heads of households were men, with the remainder being female household heads that were widowed or divorced. During the baseline survey, the ages of interviewed household heads ranged from 26 to 83 years. The average education level of the households (47.6%) was found to be below 10th grade, with the remaining 52.4% having no formal education at all. In Mirab azernet, a large proportion of sample respondents ranked bacterial wilt as a first problem (59.1%), followed by a sheath rot (14.7%), porcupine (8.2%), and corm rot (6.4%), whereas in Cheha district, bacterial wilt ranked first (49.1%), followed by corm rot (13.9%), porcupine (7.1%), and a sheath rot (5.2%) (Figure 2).

The trend of Enset production over the last 20 years varies across both surveyed areas. According to data from end line survey, approximately 78.2% and 86.7% of respondents from Cheha and Merab Azernet, respectively, reported that enset production was declining due to BW. Bacterial wilt control strategies by itself reduce the productivity of enset crop since farmers rough out the infected enset from the field. The study's findings were consistent with those of Anita et al. [12] and Endale et al. [13], who reported enset crop production losses in terms of area and productivity due to bacterial wilt. In addition to the impact of disease, farmers reported that poor soil fertility, fragmented or arable land shortage, poor management, consumption pressure, and the replacement of enset with other crops all contribute to low crop productivity. Due to the lack of effective disease control strategies and the disease's aggressiveness, farmers in the area replaced the enset crop with potato and other annual crops. Similarly, Yemataw et al. [14] and Zerfu et al. [15] reported the replacement of enset crop with another crop as a result of bacterial wilt disease.

A large number of farmers were aware of BW, its symptoms, and the methods of transmission and spread, but they were still unable to effectively control the disease. Farmers also have different perspectives on the means of BW transmission and spread. The majority of respondents (47.2%) in Cheha and 55.2% in Merab Azernet identified contaminated tools as a means of disease transmission. Respondents also mentioned that animal dung, infected plant debris, wild animals, insects, and wind are the most common modes of BW transmission. In the majority of surveyed areas, disease spread is primarily through contaminated farm tools and pruning knives. In the majority of surveyed areas, contaminated farm tools and pruning knives are the primary way of disease transmission. The study's findings are consistent with those of Addis et al. [16], who found that garden tools play an important role in the mechanical transmission of bacterial wilt. However, the potential transmission probability of bacterial wilt pathogen by animal dung is not well investigated scientifically. Enset grower practiced preventive methods to manage BW. Similarly, Kusse et al. [17] reported potential BW control measures through preventive methods such as disinfecting/flaming Enset cutting tools after use, preventing animals from browsing infected plants, fencing infected sites, and rigorous removal of infected plants and Enset residue. Farmers' awareness of symptom identification increased over time following intervention. Based on the end-of-survey results, farmer awareness of symptom identification increased from 84.2% to 98.3%. Farmers can identify the disease simply by looking for wilting leaves and the appearance of a pale to yellow ooze from a cut pseudo stem.

Several enset cultivars were identified in both districts. A total of 16 enset clons at Cheha district and 20 enset clones at Merab Athernet were assessed for their reaction to bacterial wilt with their respective purpose described on the following Table 1. Mirab Athernet had the highest enset clone diversity compared to Cheha district. Enset farmers commonly grow these clones for a specific purpose. Farmers classified the clones based on Kocho, bulla, and fiber productivity; medicinal values; and varietal response to bacterial wilt disease. A large number of enset clones have been used for food purposes in both districts.

The disease affects the crop at all developmental stages and divers range of reaction were observed among enset clone interims of resistance and susceptibility to the pathogen and none of the clones are found to be free from the BW disease symptoms except for the clone Kembat at both districts. This suggest that there was no was no enset clone that was completely resistant to bacterial wilt disease. Enset clones, namely Yirgiye, showed resistance, while Badedet, Anqefuye, Nechew, Yeguarye, and Yefereze displayed moderately resistant reaction and exhibited low disease infection. Enset clones with low BW disease infections (0-20%) can be considered as resistance/tolerant to the pathogen, while enset clones with a showed a high severity index (60-100%) have been identified as highly susceptible to the BW pathogen. Handoro and said [26] examined the response of 80 corms of enset clones to *Xanthomonas campestris* pv. *musacearum* and revealed significant differences in response to the bacterial wilt pathogen. Most majority of identified enset clones (82.7%) showed a susceptible response to the disease (Table 1). However, the previously identified resistant enset clone such as Badedet [18] loses its resistance over time. This could be due to the development of an aggressive strain of bacterial wilts within the host.

The distribution of the disease varied greatly with altitude. A higher disease pressure was observed in the higher altitude range than in the lower altitude range. Consistent with these results, Brandt et al. [19], Maina et al. [20] and Wolde et al. [7] reported that BW levels are higher in highlands than in lowlands. The perceptions of farmers in terms of seasonal variability of the pathogen varied. About 41.3% of the respondents believe that the cold season is favourable for the occurrence and development of BW. Some studies also showed that humidity and moisture (rainfall) and leaf wetness as an important factor in increasing the survival, establishment and spread of BW in plants [20]. While 34.8% of farmers believe that the dry season favors for the development of disease. The results of the studies were in line with the findings of Tripathi et al. [21] and Shimwela et al. [22] who reported that the dry season, which is more favourable for BW, is more noticeable compared to the cool season.

Table 1. Enset clone types, uses and responses to BW at Cheha and Mirab Azernet conditions

Zone	Districts	Name of clones	Major purpose	Reactions to BW
Gurage	Cheha	Yeshirakinke	Food &Feed	Susceptible
		Wonadiye	Medicine	Susceptible
		Badadet	Medicine	Moderately Tolerant
		Gezot	Medicine	Susceptible
		Yirgiye	Medicine	Tolerant
		Amerat	Medicine	Susceptible
		Ginbure	Medicine	Susceptible
		Saphara	Medicine	Susceptible
		Inba	Medicine	Susceptible
		Nechew	Medicine	Moderatel Tolerant
		Astara	Medicine	Susceptible
		Agade	Foo&Feed	Susceptible
		Guarye	Medicine	Moderately tolerant
		Anqefuye	Food and Feed	Moderetly tolerant
		Kembat	Fiber and Feed	Tolerant
		Qibnar	Medicine	Susceptible
		Ferezye	Fiber and Feed	Moderately tolerant
Siltie	M/Azernet	Disho	Foo&Feed	Susceptible
		Zobir	Medicine	Susceptible
		Qibnar	Medicine	Susceptible
		Gimbo	Foo&Feed	Susceptible
		Moche	Foo&Feed	Susceptible
		Badadet	Foo&Feed	Moderately tolerant
		Gariye	Medicine	Moderately tolerant
		Astara	Medicine	Susceptible
		Agade	Food & Feed	Susceptible
		Aywongna	Food & Feed	Susceptible
		Kembat	Fiber and feed	Tolerant
		Keset	Food & Feed	Susceptible
		Asheqit	Medicinal	Moderately tolerant
		Weshemeja	Food & Feed	Susceptible
		Sherte	Food & Feed	Susceptible
		Hayro	Food & Feed	Susceptible
		Xororo	Food & Feed	Susceptible
		Bosoro	Food & Feed	Susceptible
		Benezhe	Food & Feed	Susceptible
		Hiniba	Food & Feed	Susceptible

According to field assessment, more severe wilting was observed in mature enset plant than in young ones in most of farmers' field. This may be due to a long exposure time of the host to the pathogen. The pathogen invades systematically all tissues of the infected plant over time. The disease infects the plant at any stage of growth. The result of the study agrees with the finding of Wolde et al. [7], McKnight et al. [23], Oli et al. [24], Desalegn et al. [25], Handoro et al. [26], and Ambachew et al. [27] who reported that enset bacterial wilt affects all phase of plant development. According to the response of respondent, enset bacterial wilt pathogen can survive within the soil and different enset product for long period of time. Similarly, Handoro [28] reported that BW in Kocho can survive in Kocho for more than 14 weeks. In addition, the farmers also reported that the survival time of the pathogen was longer in soil than in the plant residues. Similarly, Mwebaze [29] reported the survival of pathogen up to three months in the soil in the absence of a host. The pathogens also survive for more than four months on host stubbles and residues Gizachew et al. [30], and Tripathi et al. [31].

After the intervention of collective action, the prevalence of the disease in each Kebele ranged from 6.25% - 19.2% (Figure 3). A Similar trend was observed in the incidence of the disease which ranged from 2.24%-13.5% (Figure 4). This difference was come from the strong commitment of enset growers and respective stakeholders in controlling bacterial wilt disease, and earlier spread of BW was the key factor in the viable difference. Bacterial wilt was influenced by plant population and intercropping practise in an areas. Wider spacing and intercropping disfavoured the movement of pathogen through different agent. The result of the study was consistent with the finding of Mekuria et al. [32], and Getachew et al. [33] who reported how the spatial distance between hosts to impede the transfer of diseases carrying propagules from infected plants to healthy plant.

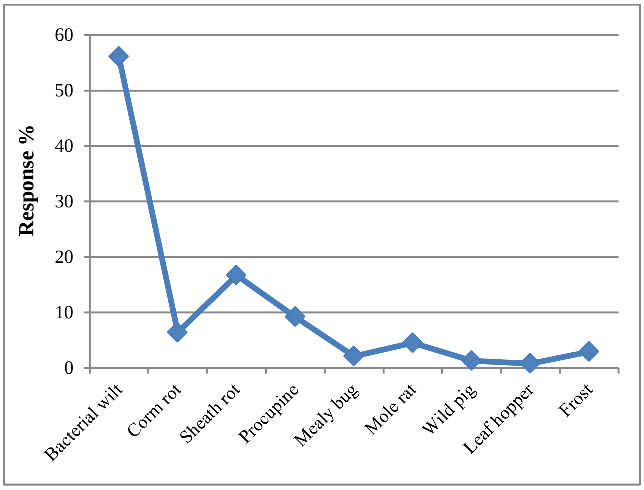

Figure 2. Proportion of sample respondents who ranked enset production constraints in Mirab Azernet district

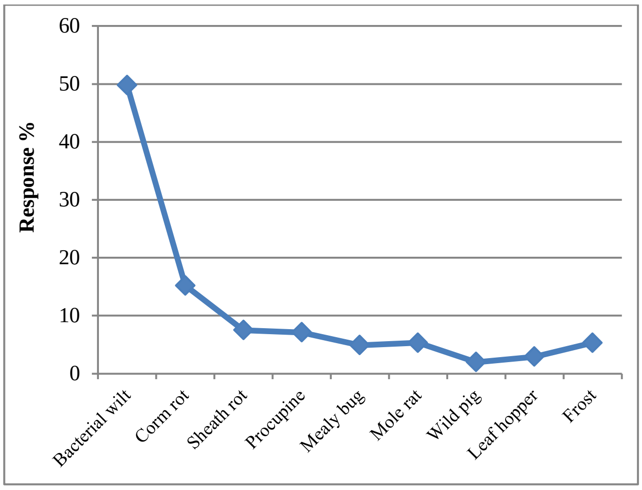

Figure 3. Proportion of sample respondents who ranked enset production constraints in Cheha district

Various preventive and curative management methods were applied by enset grower in an area. Many farmers implemented cultural practices and sanitary control measures to reduce the pathogen's inoculum load (Table 5). Similarly, Tinzaara et al. [34] reported that good sanitation, curative mechanisms, the use of disease-free sucker for planting material, crop rotation, and the use of resistant clones are all viable management options for bacterial wilt. Furthermore, cutting wilted plants, as well as burning and burying infected plants, have restricted the spread of pathogens. These practices reduce inoculum accumulation, disease development, and plant disease transmission via farm tools [8, 33]. Despite the implementation of these curative actions, the perception of farmers on effectiveness of sanitary control measures remained extremely low. As a result, farmers whose crops have been damaged by bacterial wilt must raise awareness about sanitary control measures.

Farmers in the area used botanical extract plants to treat bacterial wilt. *Fanfo* is the plant mainly used by many farmers in an area to reduce bacterial wilt either by extracting the oil or by planting around the infected enset. Similarly, Kasa and Woldeab [35] reported that botanical extracts from some plant parts showed promising effects against bacterial isolate. Farmers used enset seedling from market and home garden for transplanting purpose. Attention should be taken in to account during seedling selection against bacterial wilt. Farmers should be required to use disease-free seedlings and resistant clones to manage BW. However, the performance of available seedlings has not guaranteed complete pathogen resistance in many areas. As a result, a clear understanding of the molecular basis interaction between pathogen and host should be established by determining the pathogen population structure over large geographic areas. These contribute to the development of a database of Xcm isolates and, as a result, the best strategy for incorporating resistance genes and demonstrating the long durability of enset in a field. The movements of animal were the other contributor for the transmission of enset bacterial wilt disease. Therefore avoiding the entry of animals to the enset field by constructing fence is the other strategies of enset growers to reduce the transmission of disease.

Figure 4. Bacterial wilt infected enset at Cheha district Yewozhia Kebele

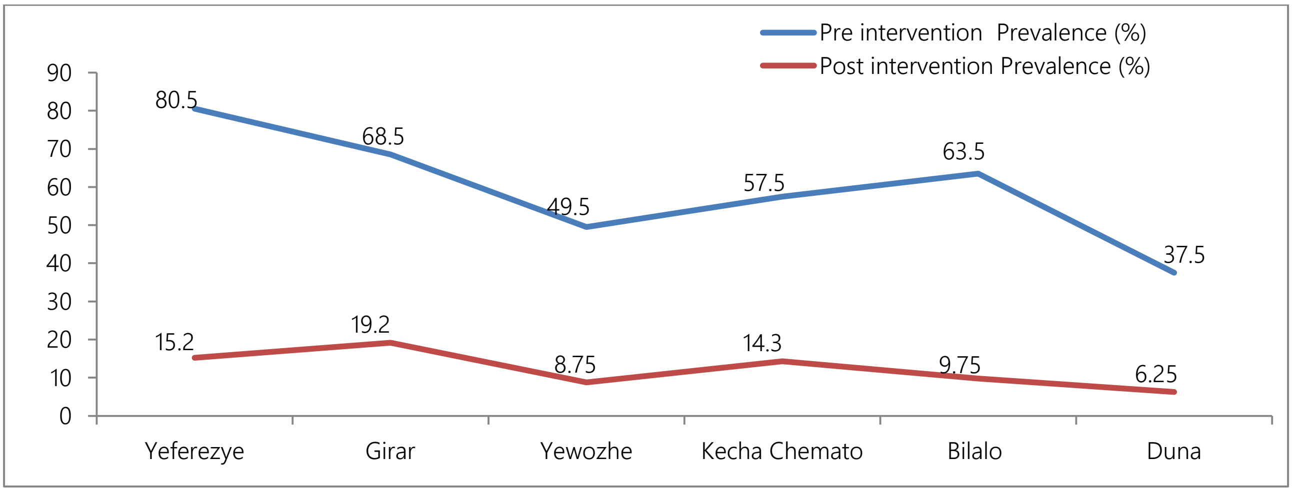

Figure 5. Prevalence of bacterial wilt pre and post intervention in Kebele

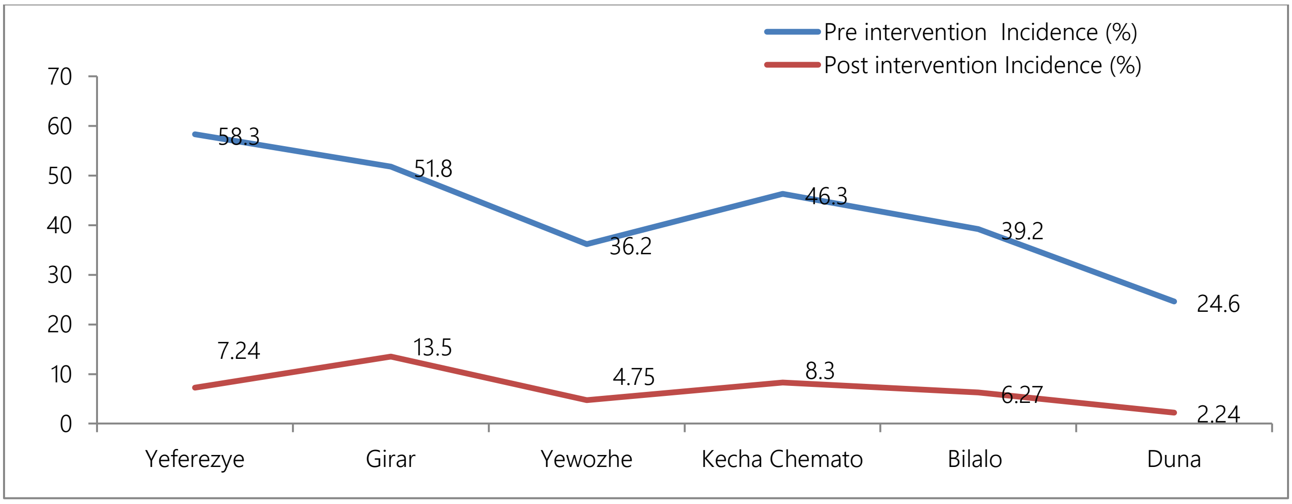

Figure 6. Incidence of bacterial wilt pre and post intervention in Kebele

Figure 5. Sanitary control measures

Farmers perception and attitude on the BW disease

According to the end line survey results, the majority of farmers (84.2%) are now aware of EBW symptoms and identifications (Table 2), and farmers' awareness of sanitary control measures has increased from 36.1 to 89.2%, but they have not implemented it properly, instead expecting chemical control from the concerned body. Disease severity was reduced to the lowest possible level using sanitary control measures. Many farmers manage bacterial wilt by removing infected plants in a mass campaign, which significantly reduces disease spread. Similarly, Yemataw et al. [36] reported a significant reduction in the disease incidence of bacterial wilt through community mobilization. Farmers also practiced cleaning and flaming equipment that had come into contact with diseased plants, as well as crop rotation with other crops if the infestation was severe. These could be a good way to slow the spread of inoculum. Implementing one or more methods may reduce disease-related yield loss, but no single action has yet been recommended to combat bacterial wilt.

Table 2. Comparative surveillance results of farmers' knowledge and perception on the BW disease

Description	Pre intervention (%)	Post interventions (%)
Symptom and identifications	84.2	98.1
Causal agent	0	49.2
Mode of transmission	51.5	86.2
Use of EBW management options		
Sanitary control measurers	27.3	7.34
Cultural control practices	71.5	94.8
IDM	12.1	75.3
Disease free and resistant and tolerant varieties	47.5	51.2
Chemical control expectations	0	2.7
Planting of Botanical (*Fanfo*) around enset plant	13.4	15.2

CONCLUSION

Understanding the epidemiology of disease which is influenced by many variables is essential before implementing any control strategy. The present study revealed the variability of EBW due agro-ecology, plant population, and growth stage and clones diversity under the field conditions. Farmers' inappropriate and traditional beliefs about reducing bacterial wilt disease do not give satisfactory results. As a result, intensive, harmonized and continuous awareness creation about improved EBW management technology should be directed toward enset growers.

These should be supplemented by a continuous public media campaign about the impact of disease and management options for reducing economic loss. Once established, EBW is difficult to control due to a lack of effective chemical or other curative treatments. Therefore, it is mandatory to use the appropriate and recommended improved management of bacterial wilt by combining the indigenous knowledge of farmers as integrated control measures with a scientific approach to sustain the smallholders' farmers. These may be applicable based on intensive research on bioactive chemicals responsible for antibacterial activity through considering resistance breeding research approach by identifying resistant genes to develop resistant clones against bacterial wilts. Additionally, extending improved technologies to other areas should be critical to minimize the spread of disease. .

DECLARATIONS

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Authors' contributions

B.T and M.G wrote and edited the manuscript. M.K Compiled and analysed the overall all data as well as wrote and edited the manuscript. Y.TS performed data collection in a field. All Authors read and agreed on the first manuscript.

Competing interests

The Authors declare no conflict of interest.

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