Vol. 19(1), pp. 33-47, January, 2023
DOI: 10.5897/AJAR2022.16243
Article Number: 1B2A7D770211
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Xanthomonas wilt of enset in Ethiopia: Geographical spread, impact on production systems and the effect of training on disease management practices

Guy Blomme[1], Elizabeth Kearsley[2], Sisay Buta[3], Alemayehu Chala[3], Ruhama Kebede[4], Temesgen Addis[5] and Zerihun Yemataw[6]

[1]The Alliance of Bioversity International and CIAT, c/o ILRI, Biodiversity for Food and Agriculture, P. O. Box 5689, Addis Ababa, Ethiopia.
[2]BlueGreen Labs, Melsele, 9120, Belgium.
[3]Hawassa University, Hawassa, Ethiopia,
[4]Independent Consultant, Addis Ababa, Ethiopia.
[5]E-nema, Company for Biotechnology and Biological Plant Protection, Schwentinental, 24223, Germany.
[6]Southern Agricultural Research Institute (SARI), Hawassa, P. O. Box 06, Ethiopia.

Received 11 October, 2022; Accepted 13 December, 2022

Xanthomonas wilt of enset is a major bacterial disease affecting the entire enset-growing belt in the southern Ethiopian highlands, impacting food security and livelihoods of small-holder subsistence farmers. Through extensive interviews and field validation visits with 354 households covering 19 communities (kebeles), we show 70% of the farms to present current and past enset Xanthomonas wilt infections, with a median of 18% cumulative plant loss across affected years since disease appearance. Training by extension services proved critical for building up farmers' knowledge on disease management, the effective implementation of disease management, and farmers' persistence to continue with enset production even when dealing with widespread infestations. After receiving training, farmers were ten times more likely to implement targeted hygienic practices and only half as likely to implement non-recommended cultural practices. Nevertheless, training in disease management did not guarantee consistent implementation by farmers. Farmers remained reluctant to dispose of infected plants, a critical part of Xanthomonas wilt management. Moreover, farmers mostly applied disease management practices once infected plants are observed on the farm, but were unaware of preventive approaches. Extension services had also not reached all communities, with 64% of the households not having received training at the time of the survey.

Key words: Disease management, Ethiopian highlands, farmer training, household surveys, *Xanthomonas campestris* pv. *musacearum*

INTRODUCTION

Enset (*Ensete ventricosum* (Welw.) Cheesman) is a major food security crop across the south and south-western Ethiopian highlands where it serves as a staple food for over 20 million people (Brandt et al., 1997; Borrell et al., 2019). While wild ensets' natural distribution is mainly found along the rift valley regions from Ethiopia to Malawi (Lock, 1993; Borrell et al., 2019), it is solely cultivated in the southern Ethiopian highlands (Brandt et al., 1997). Enset is a monocarpic perennial herbaceous plant of the Musaceae family, closely resembling the banana plant (*Musa* spp.). In contrast to *Musa* cultivars, enset is not grown for its fruits but for its underground corm and pseudo-stem base which are mainly processed into *kocho* (fermented starch), *bulla* (a premium fermented starch) and fiber (a by-product) (Borrell et al., 2019). Ensets' status as a food security crop is established through a variety of uses and benefits. The crop is robust and has high tolerance to a range of environmental conditions including both drought and heavy rains or flooding, and the occasional below zero temperatures which can occur at night at high elevation sites during the months of December and January (Degu and Workayehu, 1990; Quinlan et al., 2015; Zerfu et al., 2018). Although the crop is ideally harvested at flowering stage (5 to 8 year old plants), when biomass accumulation in the corm and pseudo-stem is at its highest level, the crop can also be harvested at earlier growth stages depending on household needs (Borrell et al., 2020). Its resilience and year-round availability, combined with the long preservation period of its fermented products, ensure the availability of a reliable food source to these Ethiopian households (Negash and Niehof, 2004; Sahle et al., 2018).

Xanthomonas wilt of enset has threatened enset production systems over the last decades. Xanthomonas wilt was first reported on enset in the 1930s (Castellani, 1939), with the pathogen *Xanthomonas campestris* pv. *musacearum* identified as the causal agent in 1968 (Yirgou and Bradbury, 1968, Young et al., 1978), later reclassified as *Xanthomonas vasicola* pv. *musacearum* (Xvm) (Studholme et al., 2020). Xanthomonas wilt has since spread across the entire enset growing region of Ethiopia. The pathogen also infects banana which is often grown on enset farms in Ethiopia (Yirgou and Bradbury, 1974; Addis et al., 2004; Shimelash et al., 2008).

Xvm is a vascular pathogen, infecting the enset plant (and *Musa* spp.) through exposed, often wounded tissue, with subsequent spread occurring throughout the plant via its vascular system. Common symptoms on both banana and enset include leaf yellowing, wilting, and the emergence of yellowish ooze from cut vascular tissue (Blomme et al., 2017).

XW of enset mainly spreads locally through the use of contaminated garden tools (mainly machetes and knives) and infected planting materials (Welde-Michael et al., 2008b; Blomme et al., 2017). The disease can also spread via mole rats and porcupines that often eat external corm pieces, and transfer disease inoculum while roaming across enset fields/landscapes (Brandt et al., 1997). Across larger distances, the use of infected leaf sheaths to wrap and transport food products to markets forms an important source of disease spread (Handoro, 2015).

Substantial efforts to manage and mitigate XW on enset have been made, and while some successes have been reported (Handoro, 2015; Yemataw et al., 2016), the disease remains prevalent across the enset growing belt in the southern Ethiopian highlands (McKnight-CCRP, 2013; Yemataw et al., 2020). The main recommended control and management practices include the sterilization of garden tools, the use of clean planting materials, the prevention of roaming animals in infected fields and the timely removal of infected plants (Quimio and Tessera, 1996; Tadesse et al., 2003; Yemataw et al., 2012; Blomme et al., 2017). A major bottleneck in the application of these practices is the incomplete knowledge of farmers of these practices and the lack of understanding how these measures aid in mitigating the spread of disease, both being strongly related to insufficient training from extension services (Yemataw et al., 2016, 2017). These gaps in knowledge, combined with practical issues at the farm level (such as lack of labour, lack of chemicals), can lead to incorrect and incomplete implementation of measures, and the prevalence and resurgence of XW across enset growing landscapes. Mitigation of XW of enset is further complicated by the current lack of fully resistant landraces (Nakato et al., 2018; Merga et al., 2019).

In this study, we investigated the presence, management level and impact of XW on enset farms across the major enset cultivation zones of the south and south-western Ethiopian highlands. Through the use of standardized interviews and field validation visits, we (1) identified the presence of XW within households/farms and assessed farmers' perception of its impact on the farm; (2) assessed farmers perception of XW tolerance of enset landraces; (3) characterized the practices implemented by farmers to manage XW on their farm, and prevent new introductions of the pathogen into their fields; and (4) assessed the impact of disease management training through extension services on farmer practices. The survey was conducted between September 2013 and October 2015, and whilst this delay should be noted, the ongoing relevance and timeliness of the study is assessed by framing the survey results within the current literature.

METHODOLOGY

Study area

Field surveys were conducted across the main enset growing belt in

*Corresponding author. E-mail: G.Blomme@cgiar.org.

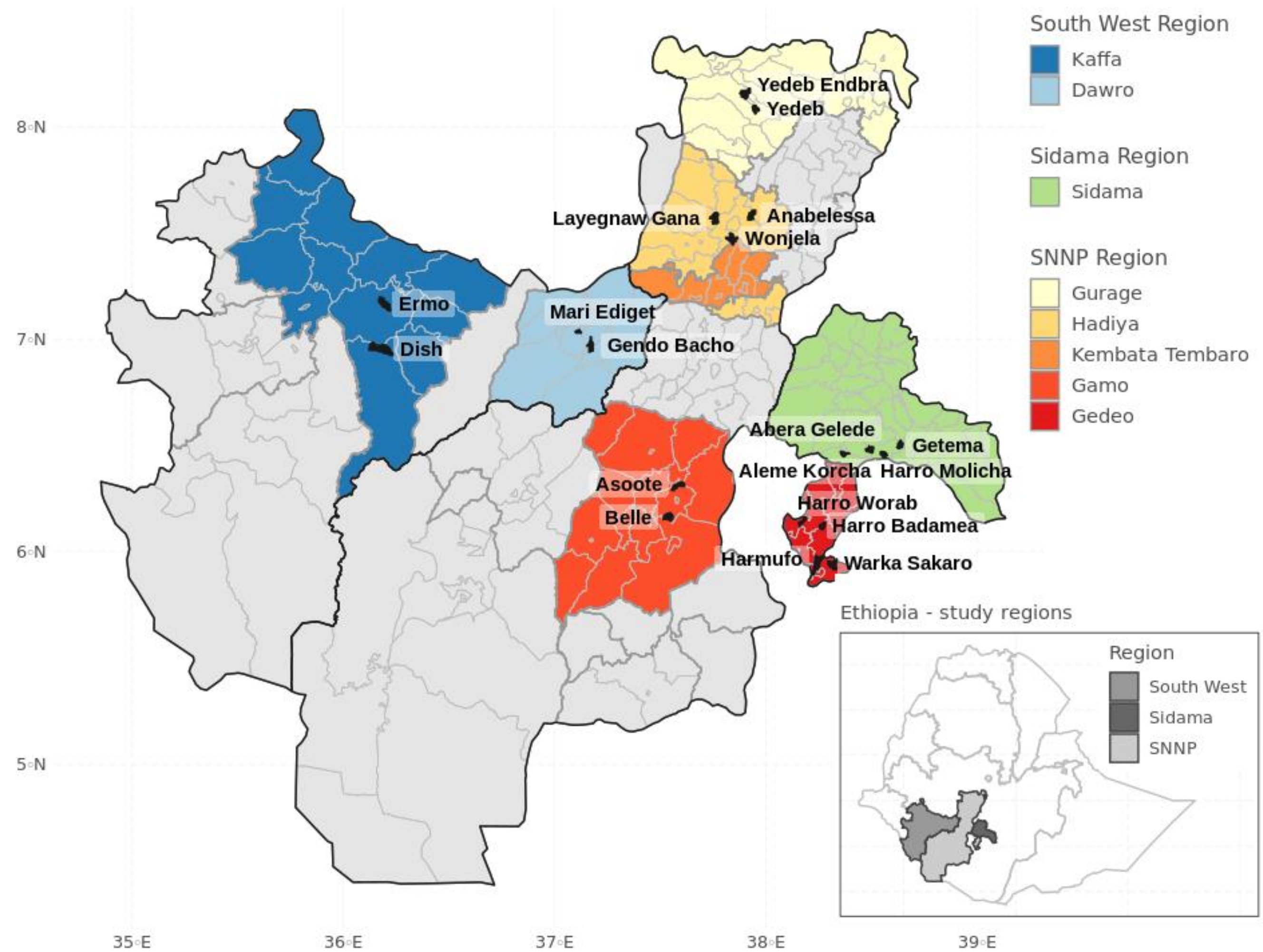

Figure 1. Study area. The survey was conducted in eight zones across the South West Region, The Sidama Region and the Southern Nations, Nationalities, and Peoples' Region (SNNPR) in Southern Ethiopia. Each zone is indicated with a different color. The kebeles (wards) participating in the survey are filled in black, with the kebele name indicated in bold.
Source: Map developed by BlueGreen Labs.

the highlands of the South-West Ethiopia Peoples' Region, the Southern Nations, Nationalities, and Peoples' Region (SNNPR) and the Sidama Region (Figure 1). The study region falls between 5.9 - 8.2°N and 36.1 - 38.7°E. Eight zones representing major ethnic groups were purposefully selected across the three regions according to the high importance of enset production systems. Five zones were selected in the SNNPR (Gurage, Hadiya, Kembata Tembaro, Gamo and Gedeo), two zone in the South West Region (Kaffa and Dawro), and one zone Sidama representing the entire Sidama region (Figure 1 and Table 1). In each zone, two kebeles (wards) with a long history in enset farming were selected. Kebeles were selected based on i) the high importance of enset in production systems and ii) the prevalence of enset bacterial wilt in the wider production landscape. In the Gedeo and Sidama zones where enset cultivation is very important and widespread, two additional kebeles were selected, in order to cover all potential diversity within these zones. One kebele in the Kembata Tembaro zone was removed from the study due to inconsistencies in the survey data. Kebeles are the smallest administrative units in Ethiopia, comprising on average 500 households per unit, or the equivalent of 3,500 to 4,000 persons, although this can vary substantially (Treiber, 2010; Anonymous, 2022). Overall, the survey covers nineteen kebeles with substantial enset production systems across fifteen woredas (districts) and eight zones. Nine to twenty-one enset-growing households were randomly selected per kebele, and an overall total of 354 households participated in the study. The selected kebeles cover an altitudinal range of 1,500 to 3,000 masl (Table 1).

Survey methods

Interviews with enset producing households were carried out by trained bureau of agriculture and extension service officers between September 2013 and October 2015. A semi-standardized questionnaire was used to interview heads of households, assisted by the person responsible for the management of the enset plantation if different. The questionnaire combined structured multiple choices and yes/no questions with open questions to allow the farmers to elaborate on specific farm aspects (available in Supplementary Information). Additional field validation visits were carried out to confirm the presence of the disease.

Table 1. Enset cultivation and the impact of Xanthomonas Wilt (XW) across the 19 surveyed kebeles.

Region	Zone	Woreda	Kebele	n	Altitude (masl)	Enset cultivation	XW impact			
						No. of plants	Prevalence (%)	No. of plants lost (cumul.)	Field-level impact (%)	Decr. trend (%)
South West	Kaffa	Decha	Ermo	16	1956 ± 12	865 ± 298^{bc}	93.8	17 ± 16^{efj}	2.0 ± 1.7^{df}	31.2
		Goba	Dish	20	2270 ± 34	2417 ± 2054^{abc}	75	463 ± 491^{cehi}	58.7 ± 105.4^{cdei}	100
	Dawro	Mari Mansa	Mari Ediget	20	2448 ± 24	1714 ± 1037^{bc}	100	213 ± 345^{cdil}	14.7 ± 26.2^{c}	100
		Mareka	Gendo Bacho	18	1704 ± 76	3437 ± 1763^{ab}	77.8	NA	NA	77.8
SNNP	Gurage	Cheha	Yedeb Endbra	20	1992 ± 17	1293 ± 673^{bc}	20	2 ± 6^{abk}	0.4 ± 1.0^{abj}	20
		Cheha	Yedeb	16	2025 ± 293	1516 ± 2711^{bc}	37.5	41 ± 97^{bjk}	5.0 ± 11.8^{bfgj}	43.8
	Hadiya	Gombora	Layegnaw Gana	21	2219 ± 36	1046 ± 486^{bc}	100	1920 ± 2181^{gm}	250.2 ± 286.5^{k}	100
		Lemo	Anabelessa	21	2321 ± 87	577 ± 523^{c}	85.7	81 ± 64^{cd}	17.9 ± 16.4^{c}	95.2
	KT	Doyogena	Wonjela	16	2194 ± 22	585 ± 165^{c}	87.5	11 ± 11^{efj}	2.2 ± 3.0^{defg}	12.5
	Gamo	Chencha	Asoote	20	2981 ± 18	3067 ± 3480^{abc}	70	369 ± 734^{cdef}	35.1 ± 100.7^{cdefg}	0
		Chencha	Belle	18	2261 ± 16	101 ± 59^{c}	100	2495 ± 2264^{g}	3490.6 ± 3683.8^{h}	94.4
	Gedeo	Yirgachefe	Harro Worab	20	1877 ± 63	2634 ± 1987^{abc}	100	186 ± 105^{il}	8.9 ± 6.0^{c}	0
		Chursa	Harro Badamea	20	2473 ± 10	1385 ± 1889^{bc}	95	441 ± 157^{hm}	50.1 ± 26.4^{i}	0
		Gedeb	Harmufo	19	2326 ± 39	686 ± 947^{c}	5.3	1 ± 2^{ab}	0 ± 0.2^{ab}	0
		Gedeb	Warka Sakaro	20	2060 ± 52	3414 ± 3404^{ab}	95	9 ± 7^{efj}	0.7 ± 1.0^{eg}	0
Sidama	Sidama	Dara	Abera Gelede	20	2744 ± 52	4555 ± 4535^{a}	0	/	/	0
		Dara	Aleme Korcha	9	1858 ± 9	3131 ± 2589^{abc}	0	/	/	0
		Hula	Getema	20	2162 ± 36	1933 ± 2150^{bc}	40	215 ± 342^{dfjkl}	16.1 ± 30.0^{cdefgj}	0
		Hula	Harro Molicha	20	2780 ± 0	2322 ± 1180^{abc}	100	2795 ± 765^{g}	128.7 ± 37.0^{k}	0

For each kebele the respective region, zone and woreda is indicated. The number of households that participated in the survey (n), altitude of the households (masl), the number of enset plants presently on the farm (# plants), the percentage of households with at least one infected plant (prevalence), the cumulative number of plants lost since XW first infested the farm, the percentage of cumulative plants lost vs the number of enset plants cultivated on the farm (field-level impact of XW) and the percentage of households reporting a decreasing trend in enset cultivation due to XW.
Standard deviations are provided. Means in a column followed by the same letter are not significantly different from each other according to Tukey's HSD test for enset cultivation and the Wilcoxon rank sum test for XW impact ($p < 0.05$).
Source: Authors

The survey results presented in this study are part of a larger survey on enset farming system characterization, and the full questionnaire covered multiple aspects of the enset farms, from socio-economic differences, to crop diversification, the specifics of enset cultivation, management and uses, and the challenges pertaining enset production (Blomme et al., 2022a, b). In this study, we focus solely on Xanthomonas wilt, the main biotic constraint for enset cultivation under small-scale farming settings. Data were collected on the prevalence of XW (that is, number of households with at least one infected plant), the field-level impact of XW (that is, the cumulative number of enset plants lost to XW since its first appearance at a site, as a percentage of the number of enset plants cultivated at time of assessment on the farm), the enset landraces affected on the farm, and the farmer's knowledge of disease management and mitigation.

Data analysis

Summarized statistics are presented at the kebele level using descriptive statistics. Responses to categorical questions are summarized as the percentage of households within a kebele giving the same response. Questions with numerical values as responses were first tested for normality (Shapiro-Wilk normality test), and differences between kebeles were either assessed through an analysis of variance followed by a Tukey test at 5% probability level for mean separation, or the Kruskal-Wallis test combined with a pairwise comparison using the Mann-Whitney U (Wilcoxon rank) test (Kruskal and Wallis, 1952). The relation between categorical and numerical responses (e.g. the implementation of specific management techniques and the impact of XW on plant populations on farm), and between two categorical responses (e.g. having received training on disease management and the implementation of management techniques) was assessed using binary logistic regressions. All analyses were performed using R version 3.6.3 (R core team, 2020).

RESULTS

Prevalence and impact of XW

A widespread prevalence of XW was reported across the entire study region, with 70% of households reporting at least one infected plant on their farm. While both the disease prevalence and impact on plant populations varied significantly between the surveyed kebeles, XW is not clearly less or more established in distinct zones across the enset growing belt.

Across affected kebeles the disease prevalence among households was very high, generally with 70 to 100% of households reporting at least one plant to have been affected on their farm (Table 1 and Figure 2a). The impact of XW on plant populations (plant loss) however varied significantly, was independent of the reported disease prevalence, and was not necessarily similar between kebeles located in the same geographical area (Figure 2b). A median 17.9% of cumulative plant loss was reported across affected farms. In several kebeles the impact remained substantially lower with cumulative plant loss values of less than 5% (e.g. at Ermo in the Kaffa zone and Wonjela in the Kembata Tembaro zone) or even 1% (e.g. at Harmufo and Warka Sakaro of the Gedeo zone and Yedeb Endbra of the Gurage zone).

In 3 kebeles, an extremely high plant loss level of >100% was reported (Table 1), indicating that the cumulative number of enset plants lost to XW since the disease first appeared at a farm is larger than the current number of cultivated plants. At the kebeles Harro Molicha (Sidama zone) and Layegnaw Gana (Hadiya zone), the cumulative number of plants lost represents one to two times the size of their current enset production (Harro Molicha: 2795 ± 765 cumulative plants lost, plant loss of 129%; Layegnaw Gana: 1920 ± 2181 cumulative plants lost, plant loss of 250%). The most extreme case was reported at the kebele Belle in the Gamo zone, where the number of plants lost is 35 times larger than the current number of enset plants cultivated. However, in this case the numbers might be skewed, as households in Belle have reportedly substantially reduced enset cultivation over past years due to the impact of XW, moving to other crops, with only 101 ± 59 enset plants currently remaining on their farm. The cumulative number of plants lost at Belle (2495 ± 2264) is similar to the high number of plants lost at Harro Molicha and Layegnaw Gana.

Households reporting perceived decreasing trends in overall enset cultivation due to XW (35% of the households; Table 1 and Figure 2c) was not related to the reported XW prevalence or plant loss level (binomial regressions, $p > 0.1$). For example, none of the severely impacted households of Harro Molicha reported a perceived reduction in their cultivation efforts of enset, while all of the severely impacted households of Layegnaw Gana reported a perceived decreasing trend in cultivation. On the other hand, 20 to 44% of the less impacted households in the Gurage zone did report to have reduced overall enset cultivation on their farm due to XW. Other factors that have reportedly led to decreasing trends in enset cultivation include land shortage and reduced soil fertility, although substantially less frequently reported than the impact of XW. On the other hand, other households report increasing trends in enset cultivation, mainly driven by a need for food security (Blomme et al., 2022b).

The reported XW prevalence and plant loss level was not related to the altitudinal position of the farms, or its associated environmental conditions.

Landraces affected by XW

A large number of enset landraces have reportedly been infected (Figure 3). While across few kebeles, households consistently report that all enset landraces are susceptible and affected by XW (Mari Ediget (100%), Belle (100%), Harro Worab (75%)), numerous farmers report specific landraces to have been affected and/or lost at their farm. Mostly, unique reports of affected landraces are made at the kebele level, with limited uniformity across kebeles. A high diversity of enset landraces exists and the specific landraces grown is highly variable across woredas and zones (Blomme et al., 2022a), explaining the highly diverse reporting of landraces affected by or lost to XW. At Harro Molicha, households report a high similarity of landraces affected by XW, with 70 to 100% of households reporting the landraces 'Ado', 'Birra', 'Gulumo', 'Midasho' and 'Sharte' to be affected, and landraces 'Agina' and 'Arisho' to have been lost (that is,

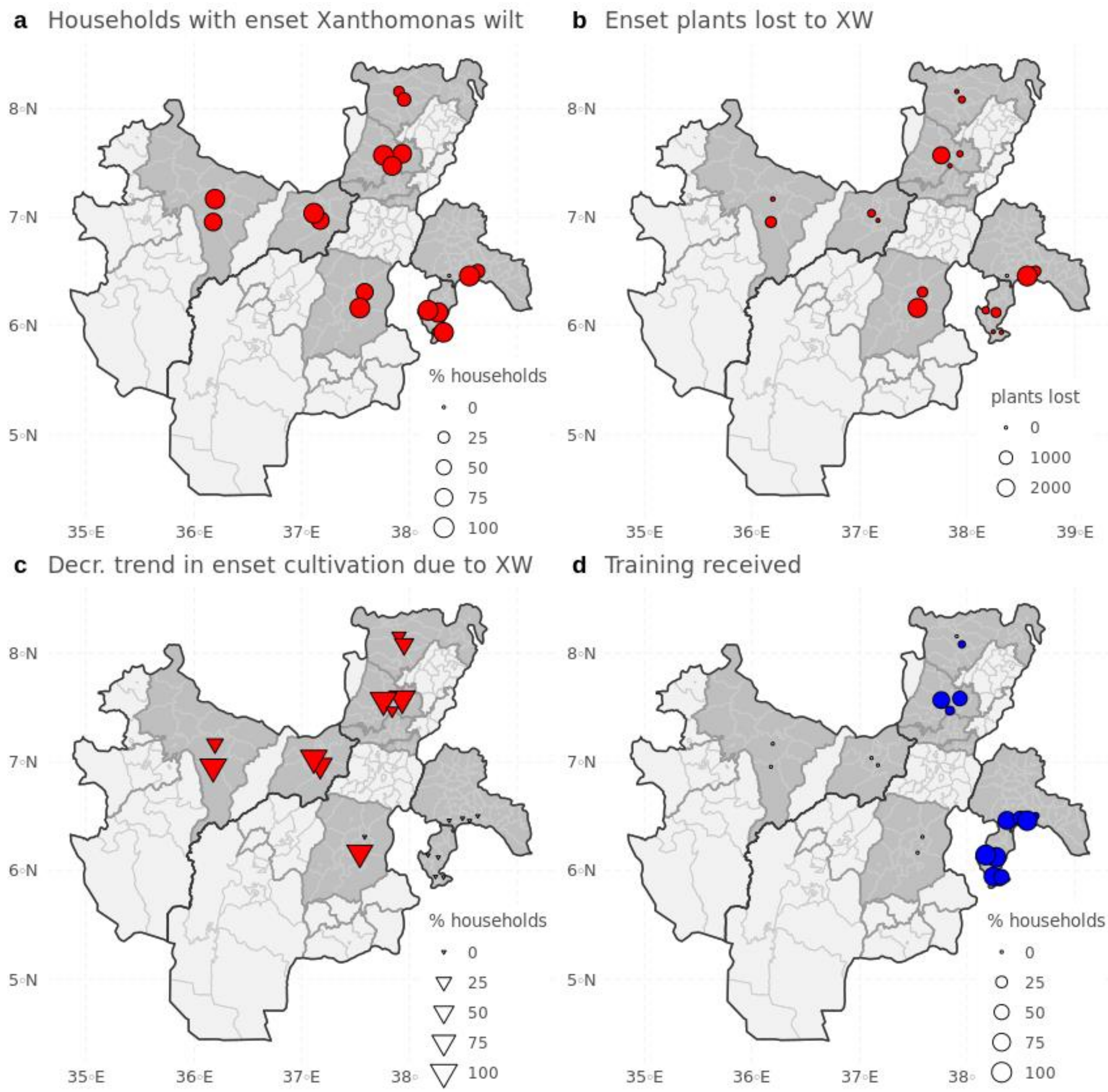

Figure 2. Xanthomonas Wilt (XW) and impact at the surveyed kebeles: (a) Households with at least one infected plant (prevalence); (b) the cumulative number of plants lost since XW first infested the farm; (c) households reporting a decreasing trend in enset cultivation due to XW; and (d) households that have received training on disease management.
Source: Maps developed by BlueGreen Labs.

no longer present on the farm due to XW). In the Kaffa zone, 75% of households in Ermo report 'Bochoo' to be affected, and 47% of households in Dish report 'Bochoo' and 'Ariko' lost from their farm.

On the other hand, a variety of enset landraces were perceived as being tolerant to XW (Figure 4), including 'Kinke' (33% at Yedeb and 25% at Yedeb Endbra of the Gurage zone), 'Gimbo' (90% at Layegnaw Gana), 'Gishira' (43% at Wonjela) and 'Noboo' (80% at Ermo). Nevertheless, contradicting reports were identified with landraces perceived as tolerant in some households, while affected by or even lost to XW in others (Figures 3 and 4, landraces indicated with an asterisk). For example, the landrace 'Genticho' was reported as resistant in multiple kebeles (Harro Molicha (95%)), Warka Sakaro (74%), Harro Badamea (53%)), while

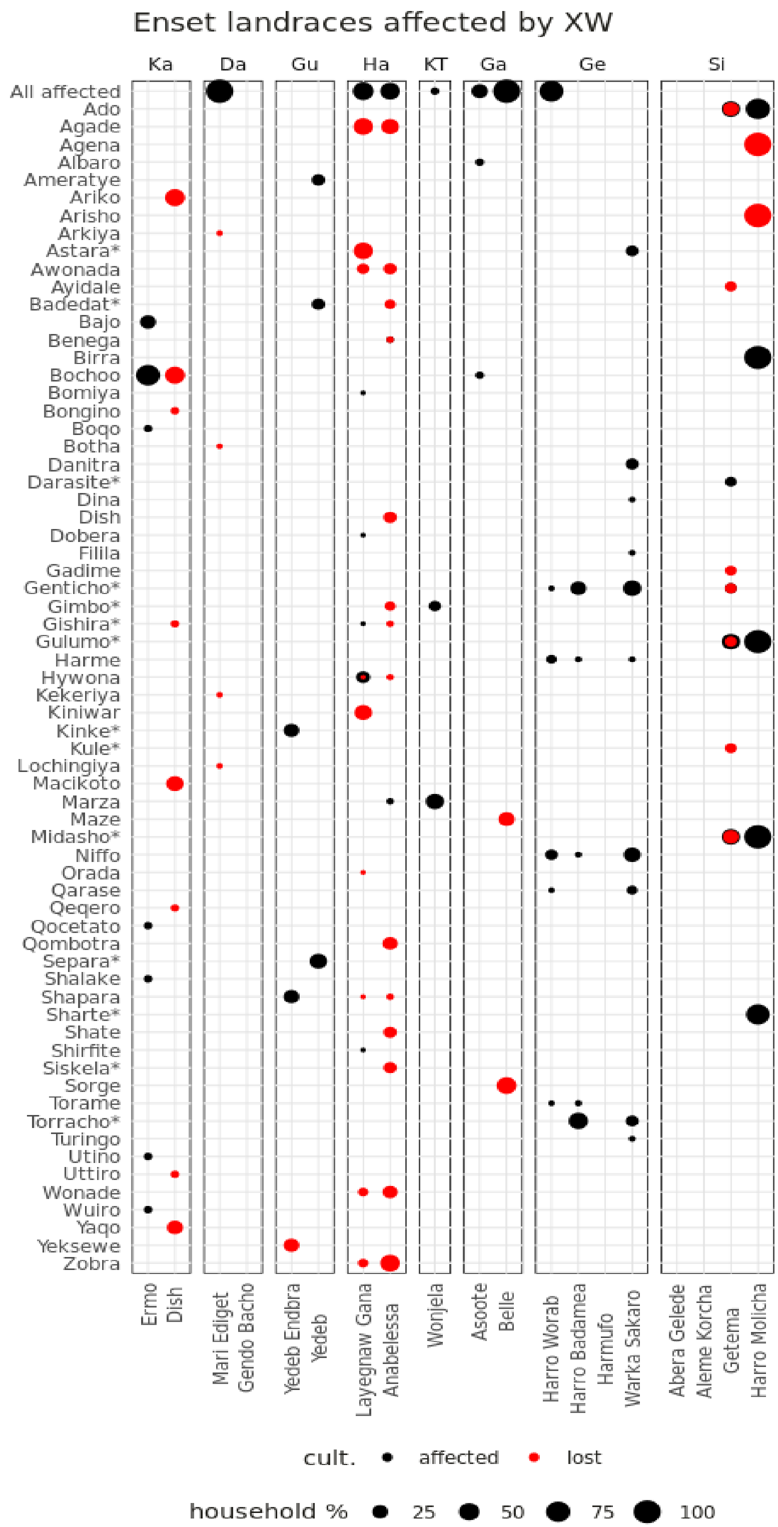

Figure 3. Enset landraces affected by Xanthomonas Wilt (XW), and those lost to households due to XW (red). The percentage of households within a kebele reporting the same landraces is indicated by the size of the circles. Landraces with an asterisk (*) have also been reported as tolerant to XW by other households (Figure 4). The kebele-level results are presented per zone (Kaffa (Ka), Dawro (Da), Gurage (Gu), Hadiya (Ha), Kembata Tembaro (KT), Gamo (Ga), Gedeo (Ge) and Sidama (Si)).
Source: Authors

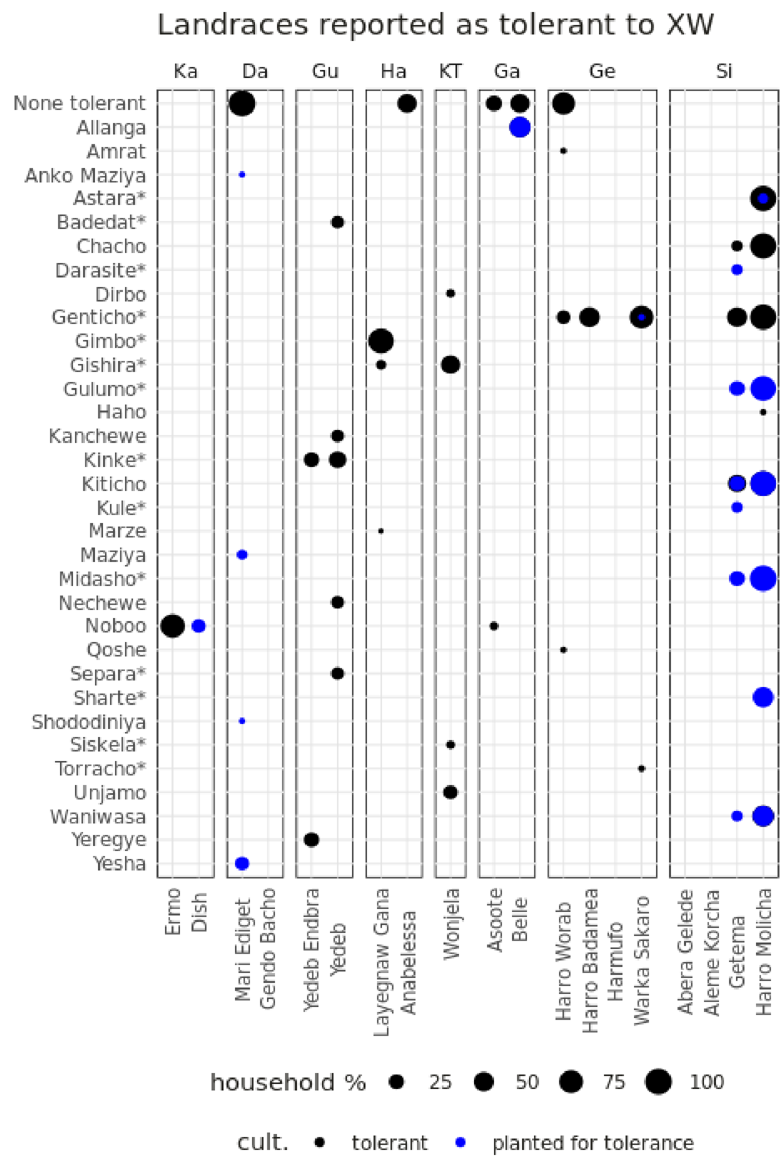

Figure 4. Enset landraces reported as highly tolerant by households, and those specifically cultivated for their tolerance (blue) as part of Xanthomonas Wilt (XW) prevention. The percentage of households within a kebele reporting the same landraces is indicated by the size of the circles. Landraces with an asterisk (*) have also been reported to have been affected by XW or even lost to the household due to XW (Figure 3). The kebele-level results are presented per zone (Kaffa (Ka), Dawro (Da), Gurage (Gu), Hadiya (Ha), Kembata Tembaro (KT), Gamo (Ga), Gedeo (Ge) and Sidama (Si)).
Source: Authors

being reported as affected by or lost to XW by other households within the same kebeles (Warka Sakaro (37%), Harro Badamea (26%)).

Disease management

Descriptive reports of controlling and preventive practices varied substantially across the households (Figure 5). Various methods of hygienic (that is, inoculum reducing) practices were the most commonly reported control practices implemented on infected fields. These practices were highly reported in the kebeles Layegnaw Gana (90.5%), Mari Ediget (95%), Harro Molicha (80%), and in kebeles in the Gedeo zone (Harro Badamea (100%), Harro Worab (90%) and Warka Sakaro (75%)). Detailed

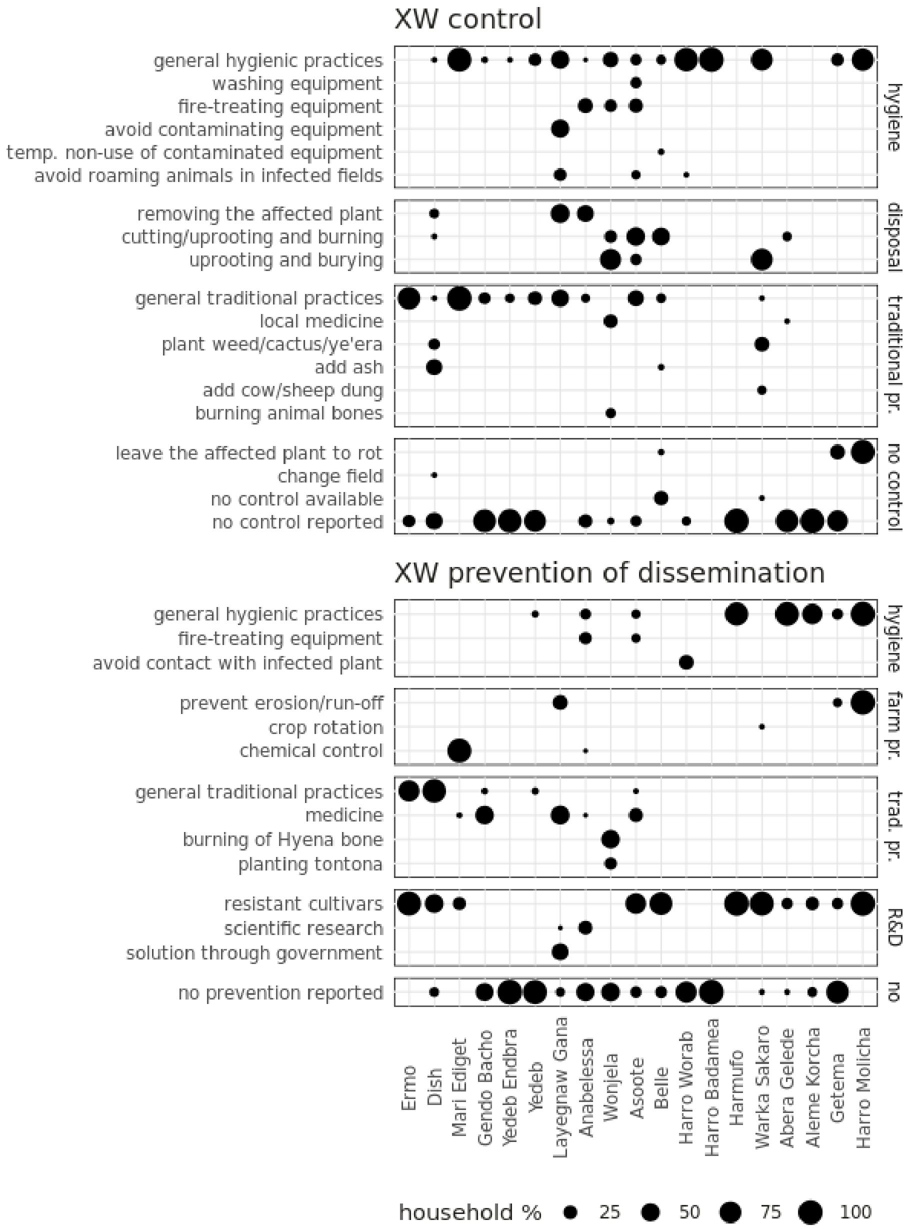

Figure 5. Knowledge on management practices reported by enset growing households (a) to control Xanthomonas Wilt when present in the farm and (b) to prevent the spread of XW. The percentage of households within a kebele reporting the same practice is indicated by the size of the circles.
Source: Authors

descriptions of hygienic practices were reported, including disinfecting equipment by putting the metal blade of the tool in fire (no info was provided by farmers on duration of practice), washing (no info was provided by farmers if only water or water plus soap was used), or in general avoiding contact of infected plants with garden tools, or by keeping roaming animals out of infected fields. Fewer households reported the disposal of infected plants/plant debris to manage XW on their farm. Reported disposal methods include cutting/uprooting and burning the infected plant debris (Asoote (50%); Belle (44%)) or burying the infected plant debris (Wonjela (87%); Warka Sakaro (75%)). Local practices, including the non-specific description of 'traditional practices' were relatively common (e.g. in Ermo (81%) and Mari Ediget (100%)) (Figure 5). The use of 'local medicine' or traditional practices such as planting cacti, adding ash or burning animal bones were described. Finally, while multiple households (35.6% of all surveyed households) were not able to respond to the question of which controlling practices were applied, only few reported that no control of XW was possible (e.g. 33% in Belle).

The farmers' knowledge of control practices significantly related to the presence of XW on their farm, with the odds of implementing hygienic practices (odds ratio (OR) 2.0, 95% confidence interval (CI) 1.3-3.2, p < 0.01), plant disposal (OR 6.8, 95% CI 2.8-16.1, p < 0.001), and local practices (OR 18.8, 95% CI 5.8-61.0, p < 0.001) significantly increasing with field level XW prevalence.

Farmer knowledge of disease prevention

Hygienic and local practices were also commonly reported as methods for prevented spread of XW (Figure 5). However, most households that identified the importance of hygienic practices for disease management did not identify the practice as part of a prevented spread strategy. Solely at Harro Molicha is hygiene widely reported for both control (80%) and prevented spread (100%). Hygiene for prevention was mainly reported in the Dara woreda of the Sidama zone (Abera Gelede (95%) and Aleme Korcha (67%)) and the Harmufo kebele (89%) in the Gedeo zone. The use of local practices for prevention was mainly reported by households in which it is also part of disease control practices (e.g. Layegnaw Gana, Wonjela, Dish and Ermo), with the use of local medicine, burning of hyena bone and planting of "tontona" (*Pycnostachys abyssinica;* a medicinal shrub with reported plant and human disease healing properties) described as methods used to prevent the introduction of XW into their fields.

The selection of tolerant landraces as an important preventive method is consistently described by kebeles in the Kaffa zone (Ermo (94%) and Dish (50%)), the Gamo zone (Asoote (65%) and Belle (83%)), at the Gedeb woreda of the Gedeo zone (Harmufo (100%) and Warka Sakaro (95%)) and at Harro Molicha (100%), with a subset of these households already implementing this strategy on their fields (Figure 4).

At the Hadiya zone, the need for additional research and development through scientific research (Anabelessa (24%)), and interventions by the government (Layegnaw Gana (38%)) were identified as important components for prevention of further spread of XW.

On average, 35.3% of the surveyed households, across the study sites, were not aware of preventive measures against the spread of XW.

Training

Extension services providing information and training on disease management were mostly targeted to households within the Gedeo and Sidama zones (kebeles Harro Badamea (94.7%), Harmufo (84.2%), Warka Sakaro (52.6%) and Harro Worab (100%); and Harro Molicha (95%), Aleme Korcha (77.8%) and Abera Gelede (45%)) and to the Hadiya zone (Anabelessa (47.6%) and Layegnaw Gana (66.7%)) (Figure 2d). These extension services were generally provided by the Ministry of Agriculture and the Bureau of Agriculture. Outside of these zones, very few of the surveyed households had received training.

Farmers who had received training on disease management and control showed a more targeted application, with a significant increase in the implementation of hygienic practices (OR (odds ratio) 10.3, 95% CI 5.0-21.1, p < 0.001), a significantly reduced implementation of 'local practices' by 50% (OR 0.50, 95% CI 0.25-0.97, p < 0.05), and significantly reduced reporting of no control (OR 0.61, 95% CI 0.41-0.90, p < 0.05). However, no effect of training was found on the farmers' implementation of, or willingness to dispose of the affected plants. Training also did not show any impact on the farmer's knowledge of measures preventing spread.

At some kebeles (e.g., Harmufo, Warka Sakaro) plant loss due to XW was reported to be very low (Table 1) most likely due to training in disease management (Figures 2b and d). However, when analyzing the data across the whole study region, no effect of training was found on XW prevalence or on plant loss due to XW on the farms. Nevertheless, training significantly reduced the decreasing trends in enset cultivation in the region, with trained farmers 77% less likely to move away from enset cultivation due to XW-related issues (OR 0.23, 95% CI 0.12-0.41, p < 0.001).

DISCUSSION

Xanthomonas wilt of enset was widespread across the entire enset growing region, with varying prevalence at the kebele level. With 70% of the assessed households reporting current and past XW infections on their farms, XW forms a major constraint on the enset farming systems. While some kebeles had been spared of infections reaching their farming community, XW was found to be well established across the entire study region. Although the survey dates back to 2013-2015, XW remains a critical disease affecting enset production along the entire enset-growing belt of the southern Ethiopian highlands. Modeling the XW distribution across the southern Ethiopian highlands, Yemataw et al. (2020) similarly observed a virtually ubiquitous presence of XW in enset farming regions. Other surveys have reported various XW hotspots throughout the years, for example with increased incidences in the Gedeo zone (McKnight-CCRP, 2013), the Hadiya zone (Wolde et al., 2016) or the West Shewa zone (Hunduma et al., 2015), but it is evident that XW forms a major constraint across all regions. No indication is found of changing XW susceptibility related to environmental conditions (in this case with altitudinal variation), although this association has been suggested (Yemataw et al., 2020; Gebre et al., 2021; Shara et al., 2021).

The reported farm-level prevalence of XW in this study is high compared to average farm/field-level prevalence of other regional surveys, for example 28% (McKnight-CCRP, 2013) and 41% (Yemataw et al., 2020). This is potentially related to the sampling design, with localized surveying of households performed at the kebele level (administrative zone consisting of 500 households or more; an equivalent of 3,500 to 4,000 persons). At this relatively small regional scale, without careful implementation of disease management and prevention practices, newly established XW infections within a community are likely to quickly spread over time to nearby farms (invasive bridgehead effect) (Lombaert et al., 2010; Ray et al., 2021). Indeed, in most of the surveyed kebeles, if XW was observed it was reported by the majority of the households (70-100%), most likely because the disease had been present for multiple years and had spread across the kebele over that time period. Accordingly, localized studies often report a higher XW prevalence, similar to this study (e.g. 89.3 and 86.7% respectively) at the Tikur Inchini and Jibat districts (Oli et al., 2014); 93% in the Gedeb woreda (Fikre, 2017); 64.4% of farms surveyed in the Yem special district (Gebre et al., 2021). High local prevalence of XW is continuously reported throughout the years, and while the prevalence can be reduced via disease management, this remains an ongoing challenge.

Not all farms were equally impacted by XW. A comprehensive study by McKnight-CCRP (2013) showed that on average 29% of enset plants were lost in infected fields. In the current survey, both substantially lower and higher impact (plant loss) was reported. Very low plant loss levels have been reported, with a minimum of 1 plant infected in several households, and plant loss levels remaining below 5% in 6 of the 19 kebeles surveyed overall. On the other hand, in 3 kebeles farmers reported a cumulative plant loss level of >100% indicating that since the disease first appeared on their farm, the equivalent (or more) number of plants of their entire enset cultivation system has been lost. Shifts in crop cultivation due to XW, as reported during the household surveys, are reported in Blomme et al. (2022b). High production losses severely impact the livelihood and food security of the households (Yemataw et al., 2017; Handoro, 2017; Yesuf 2022), and can ultimately force farmers to abandon enset production (Tadesse et al., 2003). In this study, decreasing trends in enset production have indeed been reported by farmers, although no clear relation was found with the impact of XW on the farm. The decision of farmers to reduce enset production was however dependent on whether or not they had received training in disease management. Households that had received training were hence more likely to continue with enset cultivation, even when XW had previously impacted their farms. These households had a good knowledge on how to tackle the disease and were hence not giving up.

The role of extension services is shown to be critical to improve the farmers' knowledge, the effective implementation of disease management practices, and the persistence to continue with enset production even when dealing with widespread XW infestations. Interaction with extension services overall increases the likelihood of farmers adopting management practices (Tesfaye et al., 2022), although the issues farmers faced, related to lack of training in 2013 to 2015 remain an ongoing issue today (Yemataw et al., 2016, 2017; Tesfaye et al., 2022). Farmers who had received training were 10 times more likely to implement hygienic practices and were half as likely to report the use of local practices or no awareness of control strategies. While these results show the strength and importance of extension services, a lot of room for improvement was identified. Firstly, while trained farmers were well aware of the need for hygienic practices, very few provided details on what this entailed, including washing or fire-treating of garden tools. The implementation of tool sterilization as a XW control practice has often been reported as impractical, as repetitive excessive heating of metal tool blades can damage the tools, and household bleach can be too expensive for regular use (Ochola et al., 2014; Blomme et al., 2019; Ocimati et al., 2021). The use of soapy water or boiling water could be more practical and affordable (Ocimati et al., 2021), increasing its adoption for long-term management. Importantly, the use of clean planting material was not reported by any of the households. Enset is generally propagated through plantlets obtained via macro-propagation of enset corms (Diro et al., 1996). It is hence of paramount importance that only healthy plants/corms, preferably sourced from healthy fields, are selected for enset macro-propagation. In addition, XW can be spread during transplanting steps when (asymptomatic) enset plants are uprooted and subsequently replanted at wider spacings in the same field or other fields (Brandt et al., 1997). In addition, the tradition of sharing planting material needs to be addressed to minimize the spread of XW.

Disposal of infected plant material or debris is a key aspect of the recommended disease management (Blomme et al., 2014, 2019). Infected plant debris should ideally be piled on a compost heap at the edge of a field or farm. Xvm bacteria only survive within live host tissue, and tissue decay during composting quickly removes/eliminates all Xvm bacteria (Welde-Michael et al., 2008b; Blomme et al., 2017). In addition, fresh plant debris should not be cut into very small pieces, to limit the contact of ooze with the environment. The destruction of infected plants is however very time and labor intensive and lack of labor often prevents farmers from effectively disposing of the infected plant material (Blomme et al., 2019). Cut or uprooted plants will often be left on the farm or used as livestock feed, which may lead to further Xvm inoculum transmission (Merga et al., 2019). Farmers may also be reluctant to dispose of larger/more mature infected enset plants (Yemataw et al., 2016), as several years of labor, resources and land use have already gone into the plant's production. Infected larger/more mature plants are sometimes allocated for feed to safeguard some of its value. Some enset landraces have also been shown to recover after mild infections (Said et al., 2020), and farmers might opt to wait for recovery while taking the risk of keeping infected material on the farm. The reluctance for diseased plant disposal was not reduced with the farmers who had received training. Incentive or insurance packages provided by governmental agencies to compensate for the production losses while motivating complete diseased plant disposal practices might not be feasible in rural settings in Ethiopia. Knowledge on tolerant enset landraces should be widely communicated to/shared with farming communities so that infected plants of these enset landraces could be monitored in weeks or months after disease symptom appearance, and be kept in case full plant recovery is observed. It should also be noted that any tool use on these plants should be avoided until full plant recovery or even until the plant is harvested. However, for the majority of landraces, that are susceptible to the disease, the timely removal of any infected plant should be advocated, so that disease spread and additional plant loss at field, farm and landscape level can be prevented.

While disease management practices in infected fields are critical to reduce the further spread of XW, households that did not have XW infections were generally less aware of disease management practices and less inclined to apply preventive practices. Current literature corroborates these survey results from 2013 to 2015, showing an ongoing delayed uptake of practices until after the disease is present (Pagnani et al., 2021; Tesfaye, 2022). Moreover, the farmers' knowledge and uptake of preventive practices were not related to the training they had received. Specifically, while multiple of the practices reported by the farmers are technically preventive in nature, they are not perceived as such by the farmers and only implemented when the disease has reached their fields. A better farmer understanding of disease prevention approaches (that is, prevent or limit the movement of enset planting materials, enset leaves, garden tools and domestic browsing animals across enset cultivating farms or villages, when sick plants have been reported/spotted within larger production landscapes) needs to be targeted by extension services, in enset production regions with and without XW infections. Focus on the basics of disease epidemiology and the pathogen's transmission dynamics, that is, on 'how' the disease spreads, will improve the understanding of 'why' specific practices should be applied, increasing correct implementation (Shimwela et al., 2016; Yemataw et al., 2017).

Landrace selection was reported by a substantial number of households (35%) as an important aspect of preventing XW, although only 12% had effectively planted selected landraces for their perceived XW-tolerant traits. Several tolerant enset landraces (e.g., 'Mezya', 'Bedadet', 'Hiniba', 'Mazia', 'Nobo') have been identified and shown to recover after (mild) XW infections (Welde-Michael et al., 2008a; Hunduma et al., 2015; Handoro and Said, 2016; Wolde et al., 2016; Said et al. 2020; Muzemil et al., 2021). Disease tolerance has mainly been related to long disease incubation periods, but could further be related to differences in virulence of Xvm strains or infection sites (Welde-Michael et al., 2008a; Wolde et al., 2016). Extensive screening of a wide variety of available enset landraces for their response against Xvm infections has been carried out over past decades (Welde-Michael et al., 2008a; Hunduma et al., 2015; Muzemil et al., 2021). However, in the household surveys, farmers mainly reported tolerance based on their own experience. This often translates into inconsistencies in reporting of tolerances, with landraces perceived as tolerant by some farmers while heavily affected by others. This is the case for the landrace 'Badedat', which has been shown to have tolerant characteristics (although spelled as 'Bedadet' or 'Bededet'; Muzemil et al., 2021). On the other hand, consistent reports of tolerance are found for 'Maziya' (phonetically similar to 'Mazia', shown to be tolerant (Hunduma et al., 2015; Handoro and Said, 2016)). The use of vernacular names does prove to complicate the identification of tolerant landraces. A formal taxonomic classification of enset landraces is not available (Negash et al., 2002; Bekele and Shigeta, 2011), and various vernacular names could potentially be used to describe similar landraces especially in different ethnic groups (Gerura et al., 2019; Tsegaye, 2002; Blomme et al., 2022a).

The selection of tolerant landraces by farmers remains dependent on the existing characteristics of the available landraces. While even in 2013 to 2015, farmers identified the need for research and development on tolerant and resistant enset cultivars, even today this remains a major bottleneck in XW disease management (Ajema, 2022). The genetic engineering approaches to successfully develop XW resistant banana germ plasm (Nakato et al., 2018; Tripathi et al., 2020) have over past years been transferred to enset (Merga et al., 2019). Although promising results have been obtained or are in the pipeline, the eventual delivery of these GMO enset plants to farming communities in Ethiopia faces many bottlenecks including the development of regulatory frameworks and the provision of approvals by governmental institutions. In addition, developing XW-resistant GMO enset plants for the wide diversity of enset cultivars, and obtaining enough plantlets, to reach the many farming communities, seems unachievable, even in the long run. Farmer acceptance of genetically modified enset plants is also questionable.

Conclusions

XW disease management and prevention measures including the disinfection of tools between use on different plants, preventing roaming animals in infected fields, and the rigorous removal of infected plants have been around for decades (Quimio and Tessera, 1996). These practices were scaled/fine-tuned during the XW of banana epidemic in east and central Africa (Blomme et al., 2014). Consistent implementation of these measures has however not been achieved throughout the enset growing regions of the Ethiopian highlands. Extension services have been identified as a key component increasing farmers' knowledge on effective disease management, while at the same time acting as a bottleneck. At the time of the field surveys, extension services had not reached all enset farmers leaving multiple communities in the dark on XW mitigation strategies. Moreover, farmers mostly perceive disease management as critical after the pathogen has entered a farm or production landscape, and seem unaware of preventive approaches to disease management. Improved extension services, be it through governmental institutions or non-governmental organizations, need to target (1) the full range of enset farmers; (2) knowledge-based strategies linking epidemiological facts to practical disease management, with (3) a strong focus on prevention. Continuous follow-up should be available to ensure the farmers' gained knowledge is effectively transferred to practices, and to address any issues the farmer might face integrating these practices into the overall farm management.

ACKNOWLEDGEMENTS

Partial funding to carry out the field surveys was provided by the Directorate General for Development, Belgium through the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Addis T, Handoro F, Blomme G (2004). Bacterial Wilt (*Xanthomonas campestris* pv. *musacearum*) on Enset and Banana in Ethiopia. InfoMusa 13(2):44-45.

Ajema MF (2022). Importance, biology, epidemiology, and management of Xanthomonas campestris pv. musacearum (Xcm) of Enset [*Ensete ventricosum* (Welw.) Cheesman] in Ethiopia. Net Journal of Agricultural Science 10(4):72-89.

Anonymous (2022). Wards of Ethiopia. Available at: https://en.wikipedia.org/wiki/Wards_of_Ethiopia.

Bekele E, Shigeta M (2011). Phylogenetic relationships between *Ensete* and *Musa* species as revealed by the trnTtrnF region of cpDNA. Genet. Resour. Crop Evolution 58(2):259-269.

Blomme G, Dita M, Jacobsen KS, Pérez Vicente L, Molina A, Ocimati W, Poussier S, Prior P (2017). Bacterial Diseases of Bananas and Enset: Current State of Knowledge and Integrated Approaches Toward Sustainable Management. Frontiers in Plant Science 8:1290. https://doi.org/10.3389/fpls.2017.01290

Blomme G, Jacobsen K, Ocimati W, Beed F, Ntamwira J, Sivirihauma C, Ssekiwoko F, Nakato V, Kubiriba J, Tripathi L, Tinzaara W, Mbolela F, Lutete L, Karamura E (2014). Fine-tuning banana Xanthomonas wilt control options over the past decade in East and Central Africa. European Journal of Plant Pathology 139:271-287. https://doi.org/10.1007/s10658-014-0402-0.

Blomme G, Kearsley E, Buta S, Chala A, Kebede R, Addis T, Yemataw Z (2022a). Diversity of enset indigenous farm management practices in major enset growing regions of Southern Ethiopia. The African Crop Science Journal. Under review.

Blomme G, Kearsley E, Buta S, Chala A, Kebede R, Addis T, Yemataw Z (2022b). Enset production system diversity across the southern Ethiopian highlands. Hindawi, Advances in Agriculture. Under review.

Blomme G, Ocimati W, Sivirihauma C, Lusenge V, Bumba M, Ntamwira J (2019). Controlling Xanthomonas wilt of banana: Influence of collective application, frequency of application, and social factors on the effectiveness of the Single Diseased Stem Removal technique in eastern Democratic Republic of Congo, Crop Protection 118:79-88. https://doi.org/10.1016/j.cropro.2018.12.015.

Borrell JS, Biswas MK, Goodwin M, Blomme G, Schwarzacher T, Heslop-Harrison PJS, Wendawek AM, Berhanu A, Kallow S, Janssens S, Molla EL, Davis AP, Woldeyes F, Willis K, Demissew S, Wilkin P (2019). Enset in Ethiopia: a poorly characterized but resilient starch staple. Annals of Botany 123(5):747-766. doi: 10.1093/aob/mcy214.

Borrell JS, Goodwin M, Blomme G, Jacobsen K, Wendawek AM, Gashu D, Lulekal E, Asfaw Z, Demissew S, Wilkin P (2020). Enset-based agricultural systems in Ethiopia: A systematic review of production trends, agronomy, processing and the wider food security applications of a neglected banana relative. Plants, People, Planet 2(3):212-228.

Brandt SA, Spring A, Hiebsch C, McCabe JT, Tabogie E, Diro M, Wolde-Michael G, Yntiso G, Shigeta M, Tesfaye S (1997). The "tree against hunger". Enset-based agricultural systems in Ethiopia. Washington DC, USA: American Association for the Advancement of Science P 66.

Castellani E (1939). Su un marciume dell' ensete. L'Agric. Coloniale Firenze 33:297-300.

Degu G, Workayehu T (1990). Initial results of informal survey of Areka area mixed farming zone, Wolyita Awraja. IAR working paper. Paper No.11 mimeograph. Addis Ababa, Ethiopia.

Diro M, Haile B, Tabogie E (1996). Enset propagation research review. In Enset-based Sustainable Agriculture in Ethiopia. Proceedings from the International Workshop on Enset, Addis Abeba, Ethiopia 13-20 December 1993, Abate T, Hiebsch C, Brandt SA, Gebremariam S (Eds) (Institute of Agricultural Research), pp. 242-250.

Fikre H (2017). Community based Integrated Management of Enset Bacterial wilt through Collective Action in Hallo Hartume, Gedeb. International Journal of Science and Research 6:2213-2219.

Gebre SL, Woldeyohannes A, Getahun K Regassa A (2021). Determinants of the spatial distribution of enset (Ensete ventricosum Welw. Cheesman) wilt disease: Evidence from Yem special district, Southern Ethiopia. Cogent Food and Agriculture 7:1889789.

Gerura FN, Meressa BH, Martina K, Tesfaye A, Olango TM, Nasser Y (2019). Genetic diversity and population structure of enset [*Ensete ventricosum* (Welw.) Cheesman] landraces of Gurage zone, Ethiopia. Genetic Resources and Crop Evolution 66:1813-1824.

Handoro F (2015). Community based Integrated Management of Enset Bacterial wilt Through Collective Action in Hallo Hartume, Gedeb.

International Journal of Science and Research 6(6):2213-2219.

Handoro F (2017). Community based Integrated Management of Enset Bacterial wilt Through Collective Action in Hallo Hartume, Gedeb. International Journal of Science and Research 6(6):2213-2219. DOI: 10.21275/ART20174514.

Handoro F, Said A (2016). Ensetclones responses to bacterial wilt disease (*Xanthomonas campestris* pv. *musacearum*). International Journal of Applied and Pure Science and Agriculture 2(9):45-53.

Hunduma T, Kassahun S, Hilu E, Oli M (2015). Evaluation of ensetclones resistance against enset bacterial wilt disease (*Xanthomonas campestris* pv. *musacearum*). Journal of Veterinary Science and Technology 6:1-7.

Kruskal WH, Wallis WA (1952). Use of ranks in one-criterion variance analysis. Journal of the American Statistical Association 47:583-621.

Lock JM (1993). Musaceae. *In* Polehill RM [ed.] Flora of Tropical East Africa: prepared at the Royal Botanic Gardens/Kew with assistance from the East African Herbarium. Rotterdam: AA Balkema on behalf of the The East African Governments.

Lombaert E, Guillemaud T, Cornuet JM, Malausa T, Facon B, Estoup A (2010). Bridgehead Effect in the Worldwide Invasion of the Biocontrol Harlequin Ladybird. PLoS ONE 5(3):e9743. doi:10.1371/journal.pone.0009743.

McKnight-CCRP (2013). Integrated Management of Bacterial Wilt of Enset (*Ensete ventricosum* (Welw.) Cheesman) caused by *Xanthomonas campestris* pv. *musacearum* in Ethiopia. Report: Southern Agricultural Research Institute (SARI), Ethiopia P 73.

Merga IF, Tripathi L, Hvoslef-Eide AN, Gebre E (2019). Application of Genetic Engineering for Control of Bacterial Wilt Disease of Enset, Ethiopia's Sustainability Crop. Frontiers in Plant Science, 10:133.

Muzemil S, Chala A, Tesfaye B, Studholme DJ, Grant M, Yemataw Z, Mekonin S, Magule Olango T (2021). Evaluation of 20 enset (*Ensete ventricosum*) landraces for response to *Xanthomonas vasicola* pv. *musacearum* infection. European Journal of Plant Pathology 161:821-836.

Nakato GV, Mahuku G, Coutinho T (2018) *Xanthomonas campestris* pv. *musacearum*: a major constraint to banana, plantain and enset production in central and east Africa over the past decade: banana Xanthomonas wilt (BXW). Molecular Plant Pathology 19:525-536.

Negash A, Niehof A (2004). The significance of enset culture and biodiversity for rural household food and livelihood security in southwestern Ethiopia. Agriculture and Human Values 21(1):61-71.

Negash A, Tsegaye A, van Treuren R, Visser B (2002). AFLP Analysis of enset clonal diversity in South and South-Western Ethiopia for conservation. Crop Science Journal 42:1105-1111.

Ochola D, Jogo W, Odongo M, Tinzaara W, Onyango M, Karamura E (2014). Household dynamics influencing effective eradication of Xanthomonas wilt in smallholder banana systems in Ugunja division-Kenya. African Journal of Agricultural Research 9(26):2031-2040. https://hdl.handle.net/10568/66075

Ocimati W, Tazuba AF, Blomme G (2021). Farmer friendly options for sterilizing farm tools for the control of Xanthomonas Wilt disease of banana. Frontiers in Agronomy 3:655824.

Oli M, Biratu KS, Hunduma T, Selvaraj T (2014). Assessment of disease intensity and evaluation of enset clones against bacterial Wilt (Xanthomonas campestris pv. Musacearum) in Tikur Inchini and Jibat districts of West Shewa, Ethiopia. ScieXplore: International Journal of Research in Science 1(2):1- 18.

Pagnani T, Gotor E, Kikulwe E, Caracciolo F (2021). Livelihood assets' influence on Ugandan farmers' control practices for Banana Xanthomonas Wilt (BXW). Agricultural and Food Economics 9:25.

Quimio AJ, Tessera M (1996). Diseases of enset. In: Tsedeke A, Clifton H, Steven BA, Gebre-Mariam S (Eds.). Enset-based sustainable agriculture in Ethiopia. Proceedings of the International Workshop on enset. Addis Ababa: Ethiopian Institute of Agricultural Research pp. 188-203.

Quinlan RJ, Quinlan MB, Dira S, Caudell M, Sooge A, Assoma AA (2015). Vulnerability and resilience of Sidama enset and maize farms in south-western Ethiopia. Journal of Ethnobiology 35(2):314-336.

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: https://www.R-project.org/.

Ray JD, Subandiyah S, Rincon-Florez VA, Prakoso AB, Mudita IW, Carvalhais LC, Markus JER, O'Dwyer CA, Drenth A (2021). Geographic Expansion of Banana Blood Disease in Southeast Asia. Plant Disease 105(10):2792-2800. doi: 10.1094/PDIS-01-21-0149-RE.

Sahle M, Yeshitela K, Saito O (2018). Mapping the supply and demand of Enset crop to improve food security in Southern Ethiopia. Agronomy for Sustainable Development 38:7.

Said A, Blomme G, Ocimati W, Muzemil S, Yemataw Z (2020). Can the timely removal of outer symptomatic leaves of enset plants following a tool-mediated infection with *Xanthomonas vasicola* pv. *musacearum* lead to recovery? Fruits 75(6):258-266.

Shara S, Swennen R, Deckers J, Weldesenbet F, Vercammen L, Eshetu F, Woldeyes F, Blomme G, Merckx R, Vancampenhout K (2021). Altitude and management affect soil fertility, leaf nutrient status and Xanthomonas wilt prevalence in enset gardens. Soil 7:1-14. https://doi.org/10.5194/soil-7-1-2021, 2021.

Shimelash D, Alemu T, Addis T, Turyagyenda FL, Blomme G (2008). Banana Xanthomonas wilt in Ethiopia: occurrence and insect vector transmission. African Crop Science Journal 16:75-87.

Shimwela MM, Ploetz RC, Beed FD, Jeffrey JB, Blackburn JK, Mkulila SI, van Bruggen AVC (2016). Banana Xanthomonas wilt continues to spread in Tanzania despite an intensive symptomatic plant removal campaign: an impending socio-economic and ecological disaster. Food Security 8:939.

Studholme DJ, Wicker E, Abrare SM, Aspin A, Bogdanove A, Broders K, Dubrow Z, Grant M, Jones JB, Karamura G, Lang J, Leach J, Mahuku G, Nakato GV, Coutinho T, Smith J, Bull CT (2020). Transfer of *Xanthomonas campestris* pv. *arecae* and *X. campestris* pv. *musacearum* to *X. vasicola* (Vauterin) as *X. vasicola* pv. *arecae* comb. nov. and *X. vasicola* pv. *musacearum* comb. nov. and Description of *X. vasicola* pv. *vasculorum* pv. nov. Phytopathology 110(6):1153-1160. doi: 10.1094/PHYTO-03-19-0098-LE.

Tadesse M, Kidist B, Gizachew WM (2003). Enset Bacterial wilt sanitary control in Gurage Zone. Awassa. 53:23.

Tesfaye H (2022). Influence of Livelihood Assets' on Farmers Control Practice for Enset Xanthomonas Wilt in Southern Ethiopia. Journal of Agricultural Extension P 26.

Treiber M (2010). Ethiopia: The Kebele System. Available at: https://www.refugeelegalaidinformation.org/sites/srlan/files/joomlaimages/Treiber_-_The_Kebele_System_Ethiopia_21.doc.

Tripathi L, Ntui VO, Tripathi JN (2020). CRISPR/Cas9-based genome editing of banana for disease resistance, Current Opinion in Plant Biology 56:118-126.

Tsegaye A (2002). On indigenous production, genetic diversity and crop ecology of enset (*Ensete ventricosum* (Welw.) Cheesman). Doctoral thesis, Wageningen University. The Netherlands P 198.

Welde-Michael G, Bobosha K, Addis T, Blomme G, Mekonnen S, Mengesha T (2008b). Mechanical transmission and survival of bacterial wilt on enset. African Crop Science Journal 16(1):97-102.

Welde-Michael G, Bobosha K, Blomme G, Addis T, Mengesha T, Mekonnen S (2008a). Evaluation of enset clones against enset bacterial wilt. African Crop Science Journal 16(1):89-95.

Wolde M, Ayalew A, Chala A (2016). Assessment of bacterial wilt (*Xanthomonas campestris* pv. *musacearum*) of enset in Southern Ethiopia. African Journal of Agricultural Research 11(19):1724-1733.

Yemataw Z, Borrell JS, Biswas MK, White O, Mengesha W, Muzemil S, Darbar JN, Ondo I, Heslop Harrison PJS, Blomme G, Wilkin P (2020). The Distribution of Enset Pests and Pathogens and a Genomic Survey of Enset Xanthomonas Wilt. bioRxiv. doi: Available at: https://doi.org/10.1101/2020.06.18.144261

Yemataw Z, Handoro F, Addis T (2012). Improved Enset (*Ensete ventricosum* (Welw.) Cheesman) production technologies. National Production Manual (Hawassa, Ethiopia: SARI) P 25.

Yemataw Z, Mekonen A, Chala A, Tesfaye K, Mekonen K, Studholme DJ, Sharma K (2017). Farmers' knowledge and perception of enset Xanthomonas wilt in southern Ethiopia. Agriculture and Food Security 6:62.

Yemataw Z, Zeberga A, Muzemil S, Handoro F, Yeshitla M (2016). Community mobilization and awareness creation for the management of enset xanthomonas wilt (EXW): The case of Gerino enset Tekil Kebele Administration, Gurage Zone, Southern Ethiopia. African Journal of Plant Science 7(13):1765-1781.

Yesuf HT (2022). The Influence of Livelihood Assets' on Farmers Control Practices for Enset Xanthomonas Wilt in Southern Ethiopia. Journal of Agricultural Extension 26(3):34-43.
Yirgou D, Bradbury JF (1968). Bacterial wilt of enset (Ensete ventricosum) incited by Xanthomonas musacearum sp. n. Phytopathology 58:111-112.
Yirgou D, Bradbury JF (1974). A note on wilt of banana caused by the enset wilt organism *Xanthomonas musacearum*', East African Agricultural *and Forestry* Journal 40(1):111-114.
Young JM, Dye DW, Bradbury JF, Panagopoulos CG, Robbs, CF (1978). A proposed nomenclature and classification for plant pathogenic bacteria, New Zealand Journal of Agricultural Research 21(1):153-177. https://doi.org/10.1080/00288233.1978.10427397
Zerfu A, Gebre SL, Berecha G, Getahun K (2018). Assessment of spatial distribution of enset plant diversity and enset bacteria wilt using geostatistical techniques in Yem special district, Southern Ethiopia. Environmental Systems Research 7(1):23.