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ACHIEVEMENTS, EXPERIENCES AND STRATEGIES ON ENSET (*ENSETE VENTRICOSUM* (WELW.) CHEESMAN) RESEARCH IN ETHIOPIA

Zerihun Yemataw[1,*], Sadik Muzemil[1], Agedew Bekele[2] and Eshetu Derso[3]

ABSTRACT: Enset (*Ensete ventricosum* (Welw.) Cheesman) is a perennial, herbaceous and monocarpic crop belonging to the family Musaceae. Enset based farming is an indigenous and sustainable agricultural system in Ethiopia with a total of 312,171.98 hectares of land under cultivation. The production and productivity of enset is affected by various biotic and abiotic stresses. Enset research activities have been initiated since the 1970s at different institutions. Currently, the research is nationally coordinated by Areka Agricultural Research Centre (AARC). Accordingly, the centre has been coordinating more than fifty research activities on five research objectives. The objective of this paper was to review the status of enset research and development, and provide strategies for transforming the sector. With regard to the crop improvement, the following have been sorted out: clonal identity using farmers' classification, collection and maintenance of enset germplasm, morphological and molecular characterization of enset clone, evaluation of enset varieties for drought tolerance and best quality and yield of kocho and amicho. Regarding the agronomy part, studies on comparison of whole, halved and quartered corms for planting, frequency of transplanting, spacing for planting enset on permanent field and soil fertility management have been carried out. Other attempts were also made on epidemiology and pathogenicity of EBW, and identification and control of other pests and diseases such as root mealy bug, and identification of some tolerant clones. Technologies on enset processing were developed such as: enset decorticator, squeezer and grater and all these findings and technologies have been well documented in the form of manuals, posters and leaflet forms and distributed to stakeholders and end users across enset producing zones. In order to sustain the benefits of the research and development, the project is organizing training programs and extension activities to sensitize and enhance capacity building of the farmers.

Key words/phrases: Diversity, Enset, Enset Bacterial Wilt (EBW), Genetic resources, Strategies.

[1] Southern Agricultural Research Institute, Areka Agricultural Research Centre, P.O. Box 79, Areka, Ethiopia. E-mail: yemataw.zerihun@yahoo.com
[2]Southern Agricultural Research Institute, P.O. Box 06, Hawassa, Ethiopia.
[3] Ethiopian Institute of Agricultural Research, P.O. Box 2003, Addis Ababa, Ethiopia.
*Author to whom all correspondence should be addressed

INTRODUCTION

Enset is the most widely used staple food crop for millions of people living in South and southwestern Ethiopia. It plays a central role in the economic life of the South and southwestern people (Brandt *et al*., 1997). According to CSA (2011), a total of 312,171.98 hectares of land was under enset in the country, taking up about 2.30% land area covered by all crops at country level. The number of enset trees to be harvested, in 2015 was estimated to be 112,522,152. Thus, the total produce in the form of amicho, kocho, and bulla is 23,821,849.47 quintals, 28,329,103.94 quintals and 950,414.35 quintals, respectively (CSA, 2015).

The average yield of refined enset product (kocho) ranges from 7 to 12 tons ha^{-1} $year^{-1}$. The amount of food attainable from 50-60 enset plants per year could provide enough food for an average family of 5-6 persons (Almaz Negash, 2001). Enset cultivation also protects the soil from erosion and runoff, it serves as shade and improves the microclimate for the undergrowth, and the litter from the leaves and other parts improve soil fertility (Lee and Zawdie, 1997). Research conducted on continuously enset-cultivated fields showed a higher soil nutrient status than any other fields covered with other cereal crops indicating that enset cultivation is a sustainable system with regard to maintaining soil fertility (Asnaketch Woldetensaye, 1997).

Enset research was started around the late 1960s at Debre Zeit Research Centre where some varietal evaluation for yield and bacterial wilt were conducted. Since the 1970's diverse research activities have been initiated by different researchers at different institutions. Accordingly, in 1972/73 enset clones were collected from different enset growing areas and established at Holetta Research Centre. In 1976 this collection was taken to Wolaita Agricultural Development Unit (WADU) in order to undertake variety and agronomic trials, but in early 1980s enset research in WADU was terminated in 1980. Development of enset processing devices have been developed and introduced to users at Nazreth Research Centre since1977.

In 1986 Areka Research Centre was established mainly for enset agronomy research. At the same time, trials have been started at Awasa Research Centre on enset pathology and entomology. Currently, some enset research activities are being carried out at some higher learning institutions. At present, Areka Agricultural Centre (AARC) is mandated to coordinate enset research programs across federal and regional research centres. Over the years, considerable achievements have been made in generation of new

information on enset, development of improved varieties, management practices, and promotion of improved technologies. These achievements were well documented and major gaps were identified through two consecutive international and national enset workshops carried out in 1997 (Tsedeke Abate, 1997) and 2010 (Mohammed Yesuf and Tariku Hunduma, 2012). The information contributed a lot to overcome different problems related to production and productivity of the sector. However, the ever-increasing challenges such as demand for more food, and other needs of the growing population against the changing and variability of the climate, emerging, new pests and diseases, necessitate a fundamental change in formulating and implementing agricultural research. The objective of this paper is to review the status of enset research and develop and provide strategies for transforming the sector in the country.

THE PROGRESS OF ACTIVITIES AT THE NATIONAL ENSET RESEARCH PROGRAM

The previous findings of the research activities were published at the proceedings of the International and National workshops on Enset (Tsedeke Abate, 1997; Mohammed Yesuf and Tariku Hunduma, 2012). This paper presents a review on research outputs on enset by the National Enset Research Program before and after the two workshops.

Research achievements on enset breeding

Understanding on-farm diversity management

Understanding the diversity of farmer varieties together with the knowledge of the traditional farmers is used to develop a guide map for identifying and collecting enset varieties for further breeding work. Accordingly, a number of farmers' varieties were identified from the southern parts of the country since the 1990's (Table 1).

Consequently, it was recognized that indigenous skills documented on the dispersion of enset diversity and the local knowledge base is central for *in situ* conservation of enset diversity on-farm and for the elaboration of conservation strategies. High landrace diversity in the country may indicate extended periods of enset cultivation and a more subsistence form of production.

Table 1. Number of farmer varieties recorded by different authors in major enset producing areas of Ethiopia.

No	Number of farmers' varieties	Study sites	Information source
1	76	South Omo (Ari)	Shigeta (1990)
2	158	Dawro, Gamo Goffa and Wolaita	Kefale Alemu and Sandford (1996)
3	146	Keffa-Sheka, Sidama, Hadiya and Wolaita	Almaz Negash (2001)
4	166	Hadiya, Sidama and Wolaita	Admasu Tsegaye (2002)
5	79	Sidama	Bizuayehu Tesfaye (2002)
6	111	9 different geographical sites (Wolkite, Setunae, Seltae, Bonga, Shonae, Worka, Answae, Wondo, Chencha)	Genet Birmeta (2004)
7	42	Kaffa	Yemane Tsehaye and Fassil Kebebew (2006)
8	218	7 different zones (Dawro, Gamo Goffa, Gurage, Hadiya, Kembata Tembaro, Sidama and Wolaita)	Zerihun Yemataw *et al*. (2014)
9	67	Wolaita	Temesgen Magule *et al*. (2014)
10	312	8 different zones (Dawro, Gedeo, Gurage, Hadiya, Kembata Tembaro, Sidama, Silte and Wolaita)	Zerihun Yemataw *et al*. (2016a)

Acquisition and *ex situ* conservation of enset germplasm

Ex situ conservation of plant genetic resources in gene banks is used to conserve the existing genetic diversity of cultivated species with their infra-specific taxa and wild species of potential use outside agro-ecosystems (Alvarez *et al*., 2005).

In 1986 Areka Research Centre was established mainly for enset research and since then agronomy trials have been carried out for the improvement of enset varieties. Over the years, new information was generated on enset and improved varieties, technologies and management practices were developed and introduced to end users. Accordingly, attempts were made to collect and preserve all the possible enset germplasm in Ethiopia.

Currently a total of 623 enset clones/cultivars have been collected and conserved *ex situ* by the Southern Agricultural Research Institute of Areka Agricultural Research Centre (Mikias Yeshitla and Zerihun Yemataw, 2012) from 12 major enset growing areas of Ethiopia. These were 94, 93, 71, 43, 49, 44, 49, 35, 27, 29, 57 and 32 enset accessions from Kembata/Hadiya, Dawro/Waka, Gamo/Gofa, Wolayta, Sidamo, Guragie, Yem, West Shewa/Southwest Shewa, East Shewa, Kaffa, Sheka, and Jimma, respectively. Yet, not all farmer varieties from all enset growing regions are sufficiently collected and conserved.

Variety identification and evaluation

Agro-morphological characterization

Enset exhibits a wide array of agro-morphological polymorphism. Numerous clonally stable traits are being used as markers for varietal identification and assessment of genetic diversity. Characterization of the germplasm of domesticated enset were conducted using morphological traits (Endale Tabogie, 1997; Mikias Yeshitla and Mulugeta Diro, 2009; Zerihun Yemataw *et al*., 2012a). A great deal of variability exists in quantitative and qualitative morphological, growth and yield traits among enset clones, such as maturity, kocho and bulla yield, plant height, plant pigmentation, midrib colour, petiole colour, and disease reaction (Endale Tabogie, 1997; Zerihun Yemataw *et al*., 2012a).

However, a well-established taxonomic classification and descriptor list are still lacking, and necessitates development of well-established descriptors to understand the nature of the interaction and relationships between genetic, physiological, morphological and physico-chemical characters, in order to employ intensive selection criteria effectively and efficiently.

Molecular characterization

Molecular markers are important tools to analyse genetic diversity and evolutionary relationships among and within germplasm accessions in many crop species. They are useful DNA techniques that complement morphological and physiological characterization of cultivars since they are found in the whole genome, independent of plant tissue, influence of environmental and management practices and allow cultivar identification (Manifesto *et al*., 2001; Altintas *et al*., 2008).

To this end, genetic variability of enset were investigated using Amplified Fragment Length Polymorphism (AFLP) (Almaz Negash, 2001), Random Amplified Polymorphic DNA (RAPD) (Genet Birmeta, 2004), Inter simple sequence repeats (ISSRs) (Dagmawit Chombie and Endashaw Bekele, 2011) and Simple Sequence Repeat (SSR) (Temesgen Magule *et al*., 2015) genetic markers. These works revealed a reasonable amount of variability within cultivated populations. Moreover, partitioning the existing genetic diversity within and among populations of enset also showed higher diversity within populations in many of the studies.

Currently, there is a fingerprint work at Exeter University using single nucleotide polymorphisms (SNP) markers. These markers were developed by Areka ARC selected from the largest set of enset clones (458 clones)

collected from the national core samples. Based on the analysis using various molecular markers, the study confirmed the long tradition of extensive seed-sucker exchange between enset cultivating communities in Ethiopia and these markers can also be applied to marker-assisted breeding to improve the productivity of enset.

In another effort, an *in vitro* propagation of enset showed that the method is critical to conserve germplasm and propagation of virus and bacteria free plantlets. To this effect, research has been initiated to develop efficient micro-propagation and transformation methods for enset that can be used to disseminate healthy clones and improve the productivity of the crop.

Overall, biotechnology and genomic tools are used to address production and processing challenges in enset at various institutions with limited and unsustainable funding. However, the recently available genome-wide sequence data on enset could accelerate enset research and crop improvement by identifying single nucleotide polymorphisms (SNPs) that might serve as molecular markers for marker-assisted breeding.

Evaluation of enset varieties for different uses

The goal of Enset Research Program is to enhance food security and income of enset farming communities through increased production and by improving quality of enset through efficient development of improved and sustainable technologies. The program based in Areka in Wolaita zone had a progressive result for variety selection for kocho, amicho yield and quality and EBW disease-tolerant varieties following a multi-year program of selection and a multi-location testing.

A. Evaluation for kocho

The program released six selected varieties for better kocho yield and quality. The varieties are Yanbule, Gewada and Endale (early maturing - 3 to 4 years) and Kelisa, Zerita and Mesena (late maturing - 4 to 5 years). The average kocho yield of the released enset varieties was 10 to 31 tons ha^{-1} $year^{-1}$ (Table 2) (Mikias Yeshitla and Zerihun Yemataw, 2012).

B. Evaluation for amicho

An attempt was also made to select a variety for amicho based on corm yield and quality. Four varieties have been selected and submitted for verification for release purpose (Table 3) (Zerihun Yemataw *et al*., 2016b).

Table 2. Average quantitative values of the six released enset varieties.

Trait	Variety name					
	YANBULE	**GEWADA**	**ENDALE**	**KELISA**	**ZERITA**	**MESENA**
Pseudostem height (m)	2.35	1.72	1.98	1.6	1.66	1.58
Pseudostem circumference (m)	1.44	1.22	1.3	1.27	1.32	1.13
Leaf length (m)	4.9	4.1	4.33	3.6	3.99	3.52
Leaf width (m)	1.1	0.9	0.88	0.84	0.85	0.84
Leaf number	12	11	11	11	12	11
Unsqueezed kocho (t/h/y)	31.49	22.75	26.16	23.13	24.58	19.81
Squeezed kocho (t/h/y)	21.12	15.13	17.47	15.39	16.39	13.12

Source: Mikias Yeshitla and Zerihun Yemataw (2012)

Table 3. Average values for plant growth and yield traits of highly performing enset cultivars evaluated across two locations.

Cultivar name	**PH**	**PSH**	**PSC**	**LL**	**LW**	**LN**	**C C**	**CL**	**CORM YLD**
Chohot	4.07	1	1.21	2.97	0.61	15.37	0.71	0.34	23.29
Ashakit	3.1	0.71	1.17	2.26	0.58	15.87	0.75	0.32	20.13
Bose	3.78	0.85	1.22	2.79	0.67	12.37	0.74	0.27	19.66
Gazner	3.04	0.7	0.96	2.21	0.56	12.87	0.69	0.25	18.53

PH=Plant height, PSH=Pseudostem height, PSC=Pseudostem circumference, LL=Leaf length, LW=Leaf width, LN=Leaf number, CC= Corm circumference, CL= corm length, CORMYLD = Corm yield per hectare per year

(Source: Zerihun Yemataw *et al*., 2016b)

Development of yield estimation models

Attempts were made to develop regression model which non-destructively, predicts yield of enset with better precision and simplifying yield evaluation in experiments and also overcomes the difficulties in estimating kocho yield for enset production in the different regions of the country. Mikias Yeshitla (2014) tried to estimate the yield of enset by considering different enset clones and large number of samples and the contribution of all the vegetative parameters as independent variables.

The experiment was carried out at Areka Agricultural Research on-station site on a total number of 328 enset clones. Accordingly, plant height and pseudostem circumference were the best non-destructive enset kocho yield predictors. The R^2 value for estimating fermented un-squeezed kocho yield was about 0.78 with the equation FUNK= -26.12 + 5.43 PH + 20.05 PSC describing the relationship of fermented un-squeezed kocho as a function of enset plant height and pseudostem circumference measurements. However, the employment of developed enset yield estimation model is limited to the few kocho sample clones collected from one location; models for bulla,

amicho and fiber yield were not developed. Therefore, models accounting the inter-varietal, age group, agro-ecological, and harvesting time differences should be developed to the non-destructive prediction yield model of enset plant.

Research and development experience in enset agronomy

Cultivated and wild species of enset produces seeds after a long juvenile period. Taye Bizuneh and Asrat Feleke (1966) proved that enset can be propagated through botanical seeds. This study may help in getting different varieties which is not very common in vegetatively propagated crops. However, the germination potential of these seeds is very low because of mechanical seed dormancy imposed by hard seed coat where an embryo is kept between hard micropylar collars (Mulugeta Diro and Admasu Tsegaye, 2012). Therefore, the plant is usually multiplied vegetatively using whole or split corms and grown as clones (Mulugeta Diro and Admasu Tsegaye, 2012).

Age of parent plants used for sucker production is between two and six years but usually varies from place to place. Studies were undertaken to evaluate the influence of age of parent corms on number and vigour of suckers at Areka Agricultural Research Centre (1994-1995) using one to five year old corms of Hal'a clones (Mulugeta Diro *et al*., 2001). The result showed that corms of all age group gave rise to suckers (Fig. 1). Considering the life cycle of enset crop, two to three year old parent corms can be used for sucker production.

Comparison of different corm types, stemmed from farmers' practices, was carried out at Areka Research Centre (Mulugta Diro *et al*., 2002). Whole, halved and quartered corms were compared (Fig. 2) for number and vigor of sucker production. Terefe Belehu *et al*. (1994) showed that the use of whole corm (whole and split) reduced emergence by three fold compared to use of half corm. However, halved corms resulted in vigor and more number of suckers when parent corms were uprooted, apical bud removed and planted (Table 4) (Mulugeta Diro and Admasu Tsegaye, 2012).

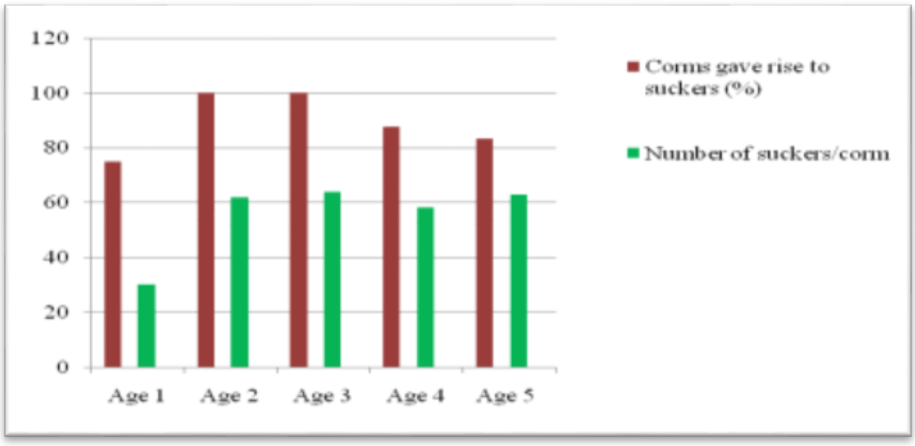

Fig. 1. Sucker production from mother corm of different ages (two years average data) (Source: Mulugeta Diro *et al*., 2001).

Table 4. Number of suckers under different propagation practices.

Propagation method	Corm type		
	Whole	**Halved**	**Quartered**
Method1	79cde	110abc	64def
Method2	113ab	141a	89bcd
Method3	94bcd	52ef	40f

Means followed by the same letters are not significantly different from each other at 5% probability level
Key: Method 1 = replanting mother corms immediately after removal of apical buds; Method 2 = mother corms not uprooted but apical buds removed; Method 3 = mother corms transferred to new holes three months after removal of apical buds. Source: Mulugeta Diro *et al*., 2002.

Fig. 2. Whole, halved and quartered corms.

Enset corm planting time

In most enset growing areas, corm planting for sucker production is exercised during the dry season. It is not known whether farmers practice is the optimum for growth and development of the planting material. Information were generated through planting corm on the 25th of every month for two years (1991-93) and under farmers own management practices such as applying farm yard manure and weeding.

The data showed that higher numbers of suckers were produced from March, May and June (Fig. 3). Performance of suckers was generally high from Jan.-March and May-June planted corms. The results showed that Jan.-June can be appropriate time of planting corms for good establishment and subsequent growth of suckers (Endale Tabogie *et al*., 1994, unpublished).

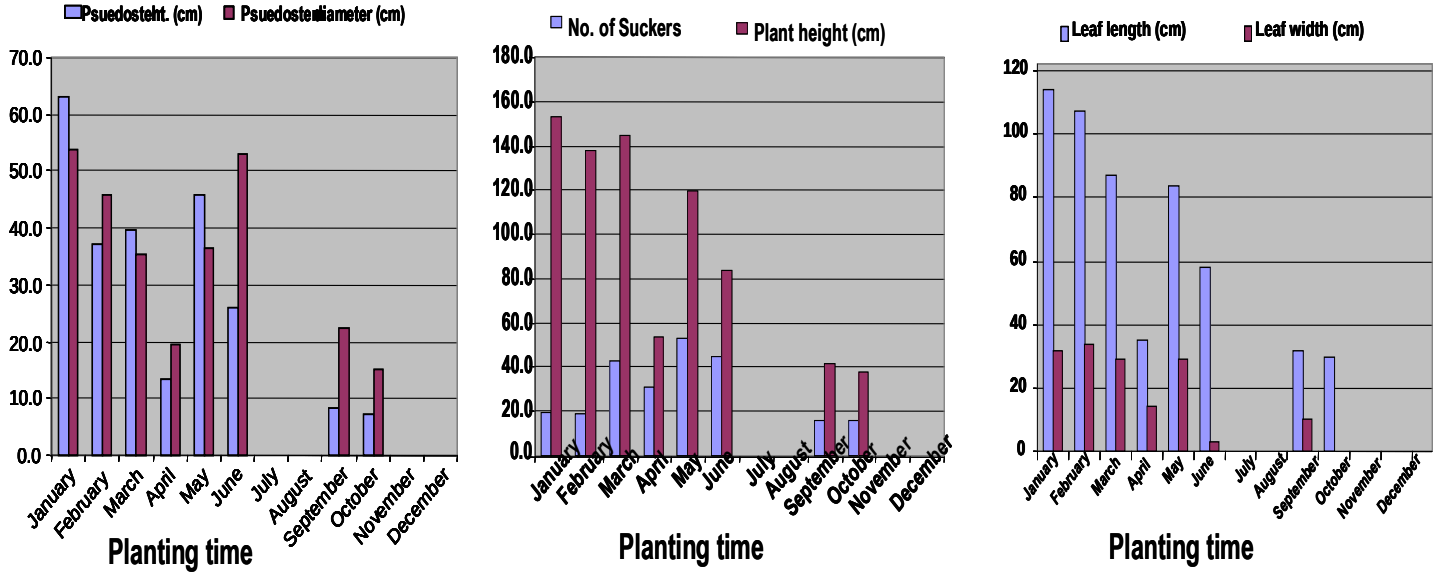

Fig. 3. Effect of planting time (month) on vegetative growth of suckers.

An attempt was also made to compare depth of planting hole for sucker production (Table 5). The whole corm was split longitudinally into two halves and planted in holes of different depth. The experiment was conducted using three years old enset plant. The result showed that in the first year, 20-30 cm depth hole gave better, but not significant number of suckers and pseudostem. Therefore, 20-30 cm depth hole was recommended for planting of halved corms (Mulugeta Diro and Admasu Tsegaye, 2012).

Table 5. Effect of depth of planting hole on emergence and growth of suckers.

Hole Depth (cm)	First year		Second year			
	No. of suckers/ corm	Pseudostem height (cm)	No. of suckers /corm	Plant height (cm)	Pseudostem height (cm)	Pseudostem diameter (cm)
20	50 a	4.4 a	60 a	71.61ab	8.77 a	2.47ab
30	36 ab	4.1 ab	36 ab	85.29 a	14.75a	3.42 a
40	35 ab	3.2 ab	26 ab	70.96ab	11.60a	2.50ab
50	13 b	2.7 ab	8 b	33.73bc	5.06ab	0.82bc
60	7 b	2.1 b	1 b	15.08 c	1.44 b	0.19 c
CV(%)	89.6	49.3	104.7	63.11	88.2	77.5

Means followed by the same letter are not significantly different from each other at a probability of 5%.

Enset plant usually has vigorous growth and wider canopy, and closer spacing affects the development of enset plants. Plant density trials were started at Holetta and later moved to Wolaita Sodo. Results showed that 3.0 m X 1.5 m was optimum spacing for enset planting (Seifu Gebremariam, 1996). Resent findings at Areka Agricultural Research Centre showed that spacing 2m between plants and 2 m between rows is appropriate for an optimum vegetative growth and yield of enset plants. Moreover, wider spacing not only improves the growth and yield of the plant but also shortens the maturity time.

Farmers apply organic waste to enset field year after year. The predominant type of fertilizer used on enset fields is natural fertilizer (farm yard manure). The results showed that an enset plant which obtained a farm yard manure of 5 to 10 kg/plant/year gave better vegetative growth and yield with an early maturity time of about 2 years (Eshetu, 2008, unpublished). It was also shown that application of N and P nutrients increased enset production at Areka. Application of 250 kg Urea and 100 kg DAP $ha^{-1}y^{-1}$ for two years resulted in better growth and yield of enset (Abay Ayalew and Mikias Yeshitla, 2011).

Research achievement and experience in crop protection

A number of disease caused by various phytopathogen and pest have been identified on enset. Diseases are caused by nematodes (Mesfin Bogale *et al*.,

2004), fungi and viruses (Jones, 2000; Mesfin Tessera *et al*., 2003), and bacteria (Dagnachew Yirgou and Bradbury, 1968; 1974). Mammals and pests such as porcupine, mole rat, and wild pigs and insects such as mealy bugs (Firdu Azerefegne *et al*., 2009) are also considered as serious problems (Fikre Handoro *et al*., 2012). However, the bacterial wilt (EBW), caused by *Xanthomonas campestris* pv. *musacearum*, has been the most threatening and economically significant (Dereje Ashagari, 1981; 1985; Eshetu Wondimagegn, 1981; Archido and Mesfin Tezera, 1993; Gizachew Welde-Michael, 2000; Mesfin Tessera *et al*., 2008; Mohammed Yesuf and Tariku Hunduma, 2012).

Enset bacterial wilt disease

Enset Bacterial Wilt was first reported on enset (Dagnachew Yirgou and Bradbury, 1968) and later on enset and banana (Dagnachew Yirgou and Bradbury, 1974) in Keffa province of Ethiopia. Then the disease was observed spreading to other enset growing areas (Dereje Ashagari, 1985; Quimio and Mesfin Tessera, 1996). Recently it has been reported that enset bacterial wilt is affecting the crop in all enset growing areas of the country (Mohammed Yesuf and Tariku Hunduma, 2012).

Characterization of *Xanthomonas campestris* pv. *musacearum* isolates

Attempts have been made to determine pathogenic variation of *Xanthomonas campestris* pv. *musacearum* using phenotypic, biochemical and rep-PCR studies (Gizachew Welde-Michael, 2000; Kidist Bobosha, 2003; Tsehay Mulaw, 2009). Results suggested that the presence of variations in Xcm among isolates. Earlier, variations among isolates was observed in some preliminary laboratory and field experiments. However, a solid information on genetic diversity of Xcm in Ethiopia is still lacking. Meanwhile, Xcm isolates from East and Central African countries proved to be genetically homogeneous (Aritua *et al*., 2007; 2008; 2009; Odipio *et al*., 2009). Recent genome-wide sequencing study suggested the existence of two major sub-lineage of the Xcm pathogen isolated from six East and Central African countries (Wasukira *et al*., 2012).

Detection of *Xanthomonas campestris* pv. *musacearum*

Different methods have been used for the diagnosis of the bacterium *Xanthomonas campestris* pv. *Musacearum* (Xcm). The earlier method used for identifying Xcm is by isolation of bacteria from its infected host and performing fatty acid and metabolic analyses (Tushemereirwe *et al*., 2004). Later, a polymerase chain reaction (PCR) assay was developed by various

researchers. Lewis Ivey *et al*. (2010) suggested a specific assay for detecting Xcm based on PCR amplification of the hrpB gene. Adikini *et al.* (2011) proposed seven PCR primer pairs that are specific for Xcm using sequences from a range of other xanthomonads. However, these two primers lack specificity for Xcm amplification. Recently, DNA primers very specific to amplify Xcm (Adriko *et al*., 2012) and the genus *Xanthomonas* (Adriko *et al.*, 2013) were developed. From genome sequence data of multiple Xcm strain, Wasukira *et al*. (2012) also generated primer sets from strain specific genomic conserved region Xcm.

Evaluation of enset cultivars against Xcm

A number of studies on artificial inoculation of Xcm against different enset cultivars demonstrated the presence of resistance/tolerance of the pathogen to certain enset cultivars (Archido and Mesfin Tezera, 1993; Gizachew Welde-Michael, 2000; Fikre Handoro and Gizachew Welde-Michael, 2007; Gizachew Welde-Michael *et al*., 2008a; Mesfin Tessera *et al*., 2008). Recent literatures also indicated the presence of cultivars with a considerable tolerance/resistance reaction towards Xcm (McKnight, 2013; Befekadu Haile *et al*., 2014; Tariku Hunduma *et al*., 2015, Mekuria Wolde *et al*., 2016) (Table 6). However, completely immune enset cultivars to Xcm have not been found yet. More research is, however, needed considering the vast wealth of enset genetic resources in different enset-growing regions.

Table 6. List and description of enset cultivars reported for their lower susceptibility to *Xanthomonas campestris* pv. *musacearum*.

No.	Name of landrace	Collection zone	Level of resistance*	Reference
1	Abatemerza	Kembata-Tembaro	R/T	McKnight, 2013
2	Alagena	Wolaita	R/T	McKnight, 2013
3	Agade	Gurage	MR	Mekuria Wolde *et al*., 2016
4	Anikefiye	Gurage	R/T	Gizachew Welde-Michael *et al*., 2008 a
5	Badadiat	West & SW Shewa	R/T	McKnight, 2013; Tariku Hunduma *et al*., 2015; Mekuria Wolde *et al*., 2016
6	Bezeriyet	Gurage	T	Gizachew Welde-Michael *et al*., 2008 a
7	Dere	Gurage	T	Gizachew Welde-Michael *et al*., 2008 a
8	Dirbo	Kembata-Tembaro	T	McKnight, 2013
9	Gefetano	Wolaita	R/T	McKnight, 2013
10	Gezewet	Gurage	R	Mekuria Wolde *et al*., 2016
11	Ginbuwa	Gurage	T	McKnight, 2013
12	Godere	Wolaita	R/T	McKnight, 2013
13	Hae'la	Kembata-Tembaro	HT	Mesfin Tessera *et al*., 2008
14	Hala-a	Dawro	T	McKnight, 2013
15	Halla	Wolaita	T	Gizachew Welde-Michael *et al*., 2008a
16	He'lla	Kembata-Tembaro	R/T	Mesfin Tessera *et al*., 2008
17	Hiniba	Kembata-Tembaro	T	Gizachew Welde-Michael *et al*., 2008a
18	Hiniba	West & SW Shewa	T	Tariku Hunduma *et al*., 2015

No.	Name of landrace	Collection zone	Level of resistance*	Reference
19	Kechere	Gurage	MR	Mekuria Wolde *et al*., 2016
20	Lemat	Gurage	T/S	Gizachew Welde-Michael *et al*., 2008a; McKnight, 2013; Mekuria Wolde *et al*., 2016
21	Mazia	Dawro	RT	Gizachew Welde-Michael, 2000; Fikre Handoro and Gizachew Welde-Michael, 2007; Gizachew Welde-Michael *et al*., 2008a; Mesfin Tessera *et al*., 2008; Tariku Hunduma *et al*., 2015
22	Nechuwe	Gurage	T/S	Gizachew Welde-Michael *et al*., 2008a; Million Tadesse *et al*., 2003; Mekuria Wolde *et al*., 2016
23	Nobo	Sheka	R/T	McKnight, 2013; Befekadu Haile *et al*., 2014
24	Onjamo	Kembata-Tembaro	T	McKnight, 2013; Annual report
25	Sorpie	Kembata-Tembaro	T	Gizachew Welde-Michael *et al*., 2008a
26	Terye	Gurage	MR	Mekuria Wolde *et al*., 2016
27	Unjeme	Kembata-Tembaro	R/T	McKnight, 2013
28	Wachiso	Kembata-Tembaro	R/T	McKnight, 2013
29	Warke Dima	West & SW Shewa	R/T	Tariku Hunduma *et al*., 2015
30	Yesha	Dawro	R/T	McKnight, 2013; Gizachew Welde-Michael, 2000
31	Yeshirakinke	Gurage	MR	Mekuria Wolde *et al*., 2016

Disease reaction as reported in the respective literatures: R= resistant, R/T= Resistant or tolerant, MR= moderately resistant; T/S= Tolerant or susceptible, S= Susceptible

Epidemiological studies on enset diseases

Xcm is reported to survive for up to 3 months in the soil in the absence of a host (Mwebaze *et al*., 2006) and more than four months on host debris and residues (Gizachew Welde-Michael *et al*., 2008b; Tripathi *et al*., 2009). The disease persists on contaminated knives for 3 to 4 days (Dereje Ashagari, 1985). Recently, the pathogen was recovered from fermented enset plant after 105 days of fermentation (Fikre Handoro, 2015).

Transmission of enset bacterial wilt from disease to healthy crop plants could occur through all possible means of contact, however, contaminated farm tools are major inoculants (Dereje Ashagari, 1985; Million Tadesse *et al*., 2003; Karamura *et al.*, 2006; Gizachew Welde-Michael *et al*., 2008b; Mikias Yeshitla *et al*., 2010). Spread by animals browsing on infected leaves, use of infected plant materials, repeated transplanting which damage corms and roots, and possibly insects visiting bacterial oozes on enset foliage may also occur (Dagnachew Yirgou and Bradbury, 1974; Eshetu Wondimagegn, 1981; Fikre Handoro *et al*., 2012). Transmission by insect vector in enset was suggested (Eshetu Wondimagegn, 1981; Fikre Handoro *et al*., 2012) but there is no clear information on insect and soil borne pathogen mediated transmission of Xcm in enset.

Natural hosts of Xcm are cultivated enset (*Ensete ventricosum*) and banana (*Musa*) (Dagnachew Yirgou and Bradbury, 1968; 1974; Thwaites *et al*., 2000). Wild Enset (*Ensete ventricosum*), which is widely distributed in East and Southern Africa, is presumed to be susceptible (Smith *et al*., 2008). In addition, plant families of Cannaceae (Cana family), Cotaceae (Cotus family), Heliconiaceae (Heliconia family), Marantaceae (Prayer-time family), Strelitziaceae (Birds of Paradise Flower family) and Zingeberaceae (Ginger family) are considered as host plants (Karamura *et al*., 2008) and could be possible source of inoculum for the pathogen (Dereje Gorfu, 2012).

Management of enset bacterial wilt

Generally, controlling bacterial diseases of plants is very difficult. The strategy developed for Xcm management includes: A) Cultural practices and sanitary control measures; B) Use of resistant/tolerant enset clones; C) Use of healthy and clean planting materials (suckers/ transplants, corms). Cultural practices and sanitary control measures were efficient to significantly reduce the spread of the pathogen (Million Tadesse *et al*., 2003).

Experiences on the management of Xcm in enset and elsewhere in banana suggest that community mobilization and awareness creation for collective management of the disease is instrumental to effectively control the disease (Million Tadesse *et al*., 2003; Eshetu Ahmed and Mohammed Yesuf, 2010; Tesfahun Fenta and Karamura, 2012). Zerihun Yemataw *et al*. (2016c) reported that sensitizing and mobilizing communities in various areas contributed to the significant decline of the incidence of the disease on the crop. Therefore, routine application of phytosanitary measures and agronomic practices minimize spread by individual and community level is currently the most effective way of managing the disease caused by Xcm.

Other enset diseases and pests

Foliar disease caused by *Phyllostical* sp., *Piricularia* sp., *Cladosporium* sp., and *Drechslera* sp., have been reported (Quimio and Mesfin Tessera, 1993). Quimio (1992) cited (Quimio and Mesfin Tessera, 1993) also reported Sclerotium wilt and root rot disease caused by *Sclerotium rolfsi*. Stewart and Dagnachew Yirgou (1967) reported the occurrence of other diseasees caused by *Phoma* sp., *Selenophom* sp., *Septroria* sp., *Thielaviopsis* sp., *Clylindroclasdium quinqueseplatum* and *Fusarium oxysporium*. Earlier, Castellani (1939) indicated that *Pseudomonas solanacearum* caused a wilt disease on enset. However, the bacterium was not isolated nor tested for its

pathogenicity. Mesfin Bogale *et al.* (2004) identified nematode species *Pratylenchus goodeyi*, *Aphelenchoides ensete* and *Meloidogyne* spp. that predominantly cause disease in enset. Temesgen Addis *et al*. (2006) also identified twelve taxa of plant parasitic nematodes associated with enset roots.

Different viruses such as uncharacterized banda viruses (Mesfin Tessera *et al*., 2003) mosaic and chlorotic stunt chlorotic streak also cause different disease of enset (Mesfin Tessera and Quimio, 1993; Quimio and Mesfin Tessera, 1996). Banana aphid, leafhopper, spider mites and mealy bug were frequently observed on both healthy and wilting enset plants and Jassid flies in virus-infected plants (Terefe Belehu and Endale Tabogie, 1989). Temesgen Addis (2005) reported that the enset root mealy bug (*Cataenococcus ensete* Williams and Matile-Ferrero) has become the most important insect pest of enset (*Ensete ventricosum*) in Gedio and Sidama zones of southern Ethiopia. These soft bodied insects feed on the corm and roots and the infested enset plants show stunted growth (Brandt *et al.*, 1997).

Overall, the management of diseases caused by these pests relies on applying the basic principles of raising health seedlings, proper plot preparation, proper crop management to maintain health plants in the field, coupled with general sanitation practices to minimize the infection. However, resistant enset cultivars and alternative disease control measures such as bio control may be necessary to combat for some of the diseases.

Research achievements and experiences on biology and management of enset Root Mealy bug

According to Terefe Belehu and Endale Tabogie (1989), banana aphid, leafhopper, spider mites and mealy bug were frequently observed on both healthy and wilting enset plants and Jassid flies in virus-infected plants. Usually these insects were suspected in transmitting bacterial wilt. However, recent survey on enset root mealy bug damage has revealed that it incurred great loss in enset production especially in Gedio and Sidama zones. These soft bodied insects feed on the corm and roots and the infested enset plants show stunted growth (Brandt *et al.*, 1997). The wild animals such as mole rat usually feed on the corm and pseudostem of enset cause considerable damage of enset.

Research on enset processing

Enset processing (which includes scraping, pressing and extraction of bulla) is carried out using traditional tools which are not efficient and are unhygienic (Deribe Kifle, 1996). Lack of labour and time-saving devices is one of the major difficulties in the day-to-day activities of women processors. The heavy work load demands more women's time and energy with less attention given to their child and family feeding responsibilities.

The impact of improved processing devices which were developed by different institutions was quite limited (Admasu Tsegaye, 2002). However, several institutes such as Nazareth Agricultural Research Centre, Hawassa University and Rural Technology Promotion Centres have developed and distributed enset decorticators, bulla squeezers and corm graters (Fig. 4). Different NGOs and governmental bodies were involved in the distribution of the devices. To make these improved devices more efficient they should be revised and modified based on feedback collected from end users. When developing rural technologies design developers should make their works more participatory to come up with appropriate technologies.

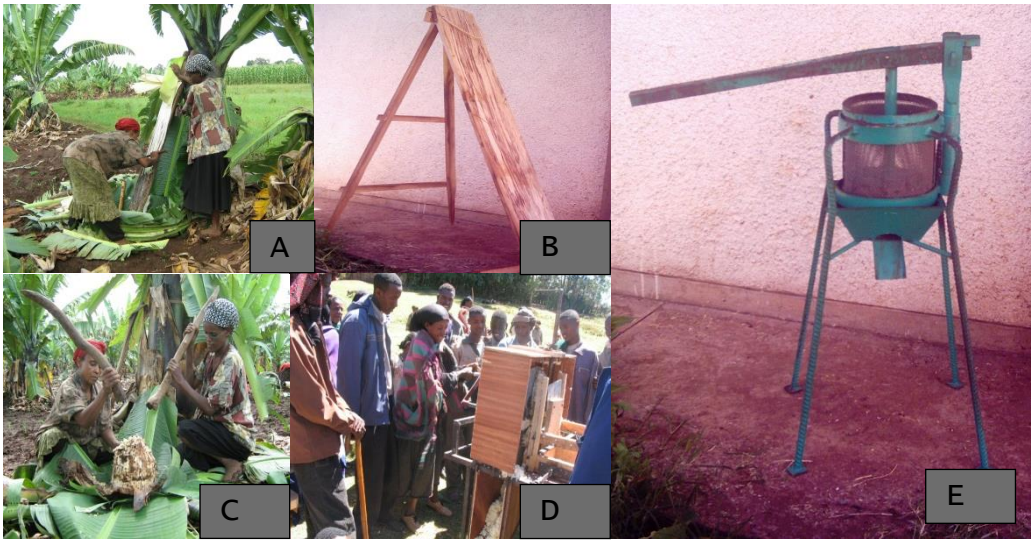

Fig. 4. Enset processing devices: Traditional (A) and improved (B) enset decorticators; Traditional (C) and improved (D) Pulverizer; Improved bulla squeezer (E).

Production packages and technology compilation and dissemination

All the currently available improved enset production, bacterial wilt management and other relating technologies with their recommendations have been compiled, documented and published into easily understandable manual, leaflets and posters form and disseminated to the targeted enset producing areas and regions of Ethiopia (Fig. 5) (Zerihun Yemataw *et al*., 2012b).

Fig. 5. Technology packages (A) Manual; (B) Poster; (C) Leaflets.

FUTURE STRATEGIES

- Strengthened integrated management of Xanthomonas wilt (EBW) and other diseases.
- Strengthened community mobilization and awareness creation about EBW disease through Participatory Development Communication (PDC) approach.
- Strengthened exhaustive collection and *in vitro* conservation

facilities should be conducted on wild, cultivated and other species.

- Strengthened morphological and molecular characterization by encompassing a large number of accessions.
- Starting new varieties development through biotechnology based breeding (breeding for host-plant resistance to pathogens and pests in enset).
- Sustainable intensification of enset-based cropping systems.
- Improvement of the efficiency of processing devices: can minimize energy and time consumption and can also improve sanitary condition during processing for fermentation.
- Priority should be given to undertake controlled fermentation studies with selected culture strata and optimize the process into modern food processing technologies.

The enset research program needs to follow demand-driven approach to technical change through:

- Explicitly considering stakeholders as equal partners in determining the needs and future plans for a dynamic enset research and development;
- Building a practical and shared vision for enset R&D;
- Building better linkages with private sector organizations;
- Better links with and among institutions;
- Co-stewardship of research and service outputs with partner institutions; and
- Rapid introduction of high-impact technologies through public and private sector partnerships.

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