Enset Research and Development Experiences in Ethiopia

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The views expressed in the proceeding are of the authors and not necessarily the Ethiopian Institute of Agricultural Research (EIAR).

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<td>AARC</td>
<td>Areka Agricultural Research center</td>
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<tr>
<td>AFLP</td>
<td>Amplified Fragment Length Polymorphic DNA</td>
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<td>ARDPLC</td>
<td>Agriculture and Rural Development Partners Linkage Council</td>
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<td>ASARECA</td>
<td>Association for Strengthening Agricultural Research in Eastern and Central Africa</td>
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<td>BARNESA</td>
<td>Banana Research Network for Eastern and Southern Africa</td>
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<td>BBW</td>
<td>Banana Bacterial Wilt</td>
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<td>BBWCI</td>
<td>National Banana Bacterial Wilt Control Initiative</td>
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<tr>
<td>CBOs</td>
<td>Community Based Organizations</td>
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<td>CBT</td>
<td>Community Based Trainers</td>
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<td>CSA</td>
<td>Central Statistical Agency</td>
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<td>DAE</td>
<td>District Agricultural Extension</td>
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<td>DNA</td>
<td>Deoxyribonucleic Acid</td>
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<td>DRC</td>
<td>Democratic Republic of Congo</td>
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<td>EBW</td>
<td>Enset Bacterial Wilt</td>
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<td>ECA</td>
<td>Economic Commission for Africa</td>
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<td>EFS</td>
<td>Enset Farming System</td>
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<td>EHNRI</td>
<td>Ethiopian Health and Nutrition Research Institute</td>
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<td>EIAR</td>
<td>Ethiopian Institute of Agricultural Research</td>
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<td>ELISA</td>
<td>Enzyme-Linked Immunosorbent Assay</td>
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<td>ENC</td>
<td>Enset Nursery Center</td>
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<td>FAO</td>
<td>Food and Agriculture Organization</td>
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<td>FFS</td>
<td>Farmer Field Schools</td>
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<td>FRG</td>
<td>Farmers Research Group</td>
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<td>FTC</td>
<td>Farmers Training Center</td>
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<td>FYM</td>
<td>Farmyard Manure</td>
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<td>HARC</td>
<td>Holetta Agricultural Research Center</td>
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<td>IAC</td>
<td>Inter Academy Council</td>
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<td>IAR</td>
<td>Institute of Agricultural Research</td>
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<td>IITA</td>
<td>International Institute of Tropical Agriculture</td>
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<td>INIBAP</td>
<td>International Network for the Improvement of Banana and Plantain</td>
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<td>IPM</td>
<td>Integrated Pest Management</td>
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<tr>
<td>ISSR</td>
<td>Inter-Specific Simple sequence Repeat</td>
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<td>ITK</td>
<td>Indigenous Technical Knowledge</td>
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<td>LAB</td>
<td>Lactic Acid Bacteria</td>
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<td>MARC</td>
<td>Melkassa Agricultural Research Center</td>
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<td>MDG</td>
<td>Millennium Development Goal</td>
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<td>MoA</td>
<td>Ministry of Agriculture</td>
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<td>NAADS</td>
<td>National Agriculture Advisory Services (Uganda)</td>
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<td>NARO</td>
<td>National Agricultural Research Organization (Uganda)</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>NBRP</td>
<td>National Banana Research Program (Uganda)</td>
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<td>NGOs</td>
<td>Non Governmental Organizations</td>
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<td>NMM</td>
<td>Net Marketing Margin</td>
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<td>NPN</td>
<td>Non-Protein Nitrogen</td>
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<td>PCR</td>
<td>Polymerase Chain Reaction</td>
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<td>PDC</td>
<td>Participatory Development Communication</td>
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<td>PSCP</td>
<td>Producers' Share of the Consumers Price</td>
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<td>RAPD</td>
<td>Random Amplified Polymorphic DNA</td>
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<td>RCBP</td>
<td>Rural Capacity Building Project</td>
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<td>Rep-PCR</td>
<td>Repetitive Sequence-Based PCR</td>
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<tr>
<td>rDNA</td>
<td>recombinant DNA</td>
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<td>RTPC</td>
<td>Rural Technology Promotion Center</td>
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<tr>
<td>SNNPRS</td>
<td>Southern Nations, Nationalities and Peoples Regional State</td>
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<td>TGMM</td>
<td>Total Gross Marketing Margin</td>
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<td>UNDP</td>
<td>United Nation Development Program</td>
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<td>WHO</td>
<td>World Health Organization</td>
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<td>YPGA</td>
<td>Yeast Peptone Glucose Agar</td>
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Preface

Enset (Ensete ventricosum) is the main crop of sustainable and indigenous cropping system in Ethiopia that ensures food security for several millions of people. Approximately 20% of the total population in Ethiopia depends upon enset for food. Moreover, different parts enset are also widely used as feed, fiber and construction material. Apart from its multipurpose use the enset plant has cultural and socio-economic value mainly in the south and south-west parts of Ethiopia. Despite the enormous and diverse importance of enset in the Ethiopian agriculture, a number of production constraints are recorded, among which enset bacterial wilt caused by Xanthomonas campastris pv. Musacearum is in the forefront. The National Agricultural Research System in collaboration with local and International organizations made efforts to study the sustainable cropping system of enset thereby to ensure food security.

A National workshop on enset research and development was organized with the objective to review and compile research and development experiences with special focus on enset bacterial wilt. Participants of this National workshop include policy makers, prominent agricultural scientists, researchers, industrialist and enset farmers. The workshop mainly dealt with review papers presentation and live exhibitions. Paper presentations were focused on enset improvement, agronomy, diseases and insect pests, processing and utilization, technology transfer, role of gender on enset farming and future areas of interventions towards enset improvement and sustainable enset bacterial wilt management. The exhibition part includes achievements on enset biotechnology, enset food products and utilization, enset mechanization and industrial products of enset.

In all cases, achievements, gaps and future areas of intervention were discussed. The identified challenges and gaps will give basis for further exploitation of enset to the level of its potential. Particularly strategies for sustainable management of enset bacterial wilt were suggested and designed based on the available experiences at national and regional level. Strategies for sustainable management of banana bacterial wilt in East African countries were also reviewed for further adoption against enset bacterial wilt. It is hoped that this proceeding will serve as valuable source of information for researchers, policy makers and teaching institutions on the major production constraints and distinctive characteristic of enset cropping system.

Editors
Acknowledgements

The organizers of the workshop would like to acknowledge the Ethiopian Institute of Agricultural Research (EIAR) and Ministry of Agriculture (MoA) management for making available all the necessary facilities and providing logistic services during the conduct of the workshop. Southern Agricultural Research Institute and Areka Agricultural Research Center are also deeply acknowledged for their active involvement on the organization of the workshop. Special thank goes to Dr. Abera Deressa (Former State Minister, MoARD), Dr. Solomon Assefa (Director General, EIAR) and Dr. Adefris Teklewold (Director, Crops Research, EIAR) for their unreserved support and all the valuable inputs they provided that helped us to make the workshop a success. Last but not least the organizers would like to acknowledge the Rural Capacity Building Project (RCBP) of the Ministry of Agriculture and Rural Development for financing the workshop.
Opening Speech

II.E Ato Tefera Derbew
Minister, Ministry of Agriculture

On behalf of the Ministry of Agriculture and Rural Development and on my behalf, I would like to extend my sincere appreciation to the organizing committee of this important enset national workshop.

Ladies and Gentlemen,

Enset, a banana-like plant is known to exist in Asia and Africa. But it has been known to be cultivated as a food source only in Ethiopia. Enset is the main crop of a sustainable indigenous Ethiopian cropping system that ensures food security in a country that is food deficient.

Enset based farming is an indigenous and sustainable agricultural system in the country. Approximately more than 20% of Ethiopia’s population depends on enset for food, feed and fiber. Over 80% of enset produced in the country is grown in the south and southwestern parts of the country. Enset is a multi-purpose and multi-year crop. Due to its drought tolerance, enset plant is regarded as a priority crop in Ethiopia, where it makes a major contribution to the food security of the country. It has been known to buffer food deficit during dry spell and recurrent drought.

Ladies and Gentlemen,

Because enset is very important crop, now its cultivation is extending to the other parts of the country, where it was not cultivated widely before. One author wrote that “enest plant is everything for the farmers”; it is their food, cloth, beds, houses, cattle-feed and plates. A book, “Lost Crops of Africa” mentioned enset as “possibly no plant on earth can match enset for the number of products it provides for the poor people”. Without doubt, I dare to say, the contribution of enset plant to the growing economy of the country is tremendous especially towards the food security program.

Ladies and Gentlemen,

Though enset is such a valuable crop plant, its production is alarmingly getting threatened by various pests. Among others, bacterial wilt of enset is becoming the major concern as an important threat to enset production. In the past, various research attempts were carried out to control these economically important pests. Despite all the attempts, the problems continue on unacceptable scale and looks for integrated approach of all concerned bodies and designing of possible means to tackle it. This National workshop on Enset Research and Achievements is timely and appropriate to offer good opportunity to discuss all pertinent issues about this very
important crop plant, and design future strategic directions by involving all concerned stakeholders. Hopefully, this workshop will create a conducive platform to design research priorities, technology dissemination, and community mobilization towards sustainable management of enset production threats with major emphasis on bacterial wilt.

**Distinguished workshop Participants.**

**Ladies and Gentlemen,**

I am fully confident that your deliberations today and tomorrow will be able to build a rational and very clear objective analysis of all issues about enset and contribute to this noble goal by realizing the contribution of enset plant to the food security of the country.

Finally, I wish you all success in your deliberations and hope your discussions will be enjoyable and fruitful. With these brief remarks, I declare this National Workshop on Enset is officially open.

I thank you all.
Introduction

The Enset Farming System (EFS, hereafter) is among the backbone of Ethiopian agricultural economy. The crop accounts for the basic livelihood from 16 to 18% of Ethiopian Population. As basic diet for millions of people at various agro-ecologies, EFS has much influence on the development of rich and diversified cultures in the south and south-western Ethiopia. The early evolution of EFS is least documented. Since the last two decades, considerable attention has been given to EFS both at national and international levels.

The enset agro-ecology ranges from 1500 -1800m above sea level where the crop growth cycle takes 4-5 years under relatively warm climate; to highland regions 1850-3000m above sea level where the crop growth cycle is extended by 2 to 3 years compared to relatively low elevation and warm climatic regions. Along these climatic zones, the EFS integrates livestock husbandry with the cultivation of stimulant crops, root and tuber and spice crops in the mid altitude; cereals, pulses, oil crops, cool season vegetables and temperate fruits in the high land regions (Taye 1966/73/96 and Westphal 1975).

Regions where enset is used as major staple food are among the most densely populated in Ethiopia. In the Guraghea area, for example, 50 to 200 inhabitants per square kilometer while over 300 inhabitants per square kilometer were inhabited in Kembata, North Omo and Woliata areas. In pursuit for improving the livelihood of millions of people at various agro-ecologies, the EFS has evolved environmentally friendly agricultural practices based on the recycling of renewable resources and economic complementarities among its sub-systems of production (i.e. crops, livestock, fruits, vegetables, stimulant crops, and spices).

Hence, the technological challenges of sustainable enset farming system with more emphasis on enhancing its food and fiber production and industrial outputs are summarized in seven different sections.

Section one describes the enset farming system as a bio-dynamic sustainable agricultural practice supporting the livelihood of about 20% of Ethiopian population. This section also emphasizes the need for scientific classification of
various potential clones/varieties based on morphological, taxonomic and horticultural traits to systematically register same in the National Registry.

The second section emphasizes the conventional research challenges resolved through, agronomic, horticultural and bio-technology studies. This section also identifies institutional and researchers challenges to respond to diversified issues and problems of enset research and production system.

Section three analyzes enset research progress (over the last 25 years) based on an extensive agronomic research evaluation on more than 600 clones collected from major growing areas of the crop. Among the main research outputs included are groupings (based on growth cycle maturity) of enset clones into early, intermediate and late sets enset clones, coupled with the identification of superior high yielding enset clones for food and fiber uses. The section also reviews the need to advance research on bio-technology and screening cultivars resistance to bacterial wilt and other diseases of the crop.

The fourth section notes the new era of enset research growth and expansion along the concurrent evolution of Southern Agricultural Research Institute (SARI) and establishment of Areka Agricultural Research Center (AARC) as well as the emergence of new generation of researchers engaged on the improvement of the crop.

The cultivation of enset based on salient analysis and perspectives is discussed in section five, which deals with enset food production, nutritional values and the need to employ available technology to expand manufacturing of various fiber products both for export and domestic markets. The successful fiber manufacturing industrial growth with abaca fiber (Musa textilis) in Philippines is compared with enset fiber in Ethiopia. Even though the tensile strength and quality of abaca and enset fiber are similar, the lack of innovations by both the public and private sectors and the traditional dependence on foreign investors to launch on such ventures, remain as major setbacks in the transformation of agricultural technologies into agro-industries.

Equally important is section six, covers the analysis of the current status and the need to improve implements/devices for enset harvesting and processing. As the way forward, the last section, section seven, brings to the forefront key technological options for modernizing the EFS in order to expand economic role of enset.
Botanical Characteristics, Economic and Agronomic Classifications of Enset

Cheesman (1947) and Moore (1957) did establish basic botanical differences between the two genera i.e. *Musa* and *Ensete* of the Musaceae family. Detail description of Ensete spp. has been reported by Baker and Simmonds (1953). Morphological and cytological differences (chromosome number, pseudo-stem size and color characteristics, seed, embryo morphology and propagation method etc.) led to the transfer of about 20 species from the genus *Musa* to *Ensete*. According to Vavilove 1951 and Simmonds 1958, Ethiopia is one of the primary center of origin and diversity not only for a number of cereals (barely, durum wheat, teff), some pulse and oil crops, stimulants (*Coffee arabica, Catha edulis* etc) including enset (*Ensete ventricosum*). The wild relatives of the latter species are known to occur at lower altitudes in tropical African countries, including Kenya and Uganda south to Mozambique. The previous collections of enset clones and morphological classification and agronomic evaluation have evidenced the existence of several clones throughout Ethiopia (Annual Reports, Debre Zeit and Holleta Agricultural Research Centers from 1969 to 1975).

The establishment of Areka Agricultural Research Center (AARC in 1994) gave new impetus and thrust on enset research. The AARC collection of more than 600 clones of enset from major enset growing regions, which is recorded in Annex 2, led to undertaking agronomic and disease resistance research evaluations to identify or develop high yielding food and fiber cultivars.

Classification of enset cultivars/clones/or varieties

A national crop releasing procedure has been established whereby criteria for the various categories of crops have been stipulated as guidelines register elite varieties/clones of crops in the National Crop Register. Criterion, which are pertinent to evaluating enset clones is proposed to be included in existing guideline, which in due course can be refined to register and release new enset clones/varieties. This may include:

- Phenotypic similarity, color, and vegetative morphology (including plant and pseudo stem heights and circumstances);
- Leaf sheath and leaf characteristics, color, size, shape, umber and weight;
- Corm circumference, grated weight variation, detection of true stem, or emergence of voluntary suckers if any similar to *Musa*;
- Flower, fruits and seed morphology and variation
- Agronomic evaluation and grouping down to five best clones to produce kocho, bulla and fiber.
- Agro-ecological adaptation and dominance of clones;
• Maturity range and cycles (already in progress at ARC where clones grouped as early, intermediate, and late sets based on period of years of maturity and yield of kocho, bulla and fiber;
• Cytological investigation to detect variability of somatic cells or chromosomes; and
• Minimizing vernacular names and specific agronomic criteria;
• Types of plant (ornamental) and suitable use including for medicinal purposes; and
• Horticultural or domestication traits, yield of food and fiber.

Comments on registration, naming and release of clones/cultivars
Regarding registration and release of cultivars/or clones among the key problem include repeated vernacular names given to same or similar clone by different ethnic traditional languages. Therefore, there is need to narrow down the apparent large number of clones of enset based on morphological, taxonomic, horticultural traits, growth cycle and yield performance (food and fiber). Classification of enset based on these parameters could enable to identify clones with genetic diversity, and also save considerable time and resources in the entire research effort for identifying or developing high yielding food and fiber clones/ cultivars collected from diverse sources and regions.

Based on phenotypic characteristics such as color of leaf and pseudo-stem as well as ecological adaptation and growth performance of similar clones, but known by different vernacular names were identified in Wolaita, Kambata and Sidamo area (Endale et.al., 1996).

Research and Technology Development Challenges

Conventional research challenges
Among the persistent research challenges of EFS include:

• The generation and application of more productive technologies to substantially improve the yield of food and fiber, and also the productivity of the system in sustainable manner;
• Coping with the food security needs for the apparent population increase;
• Enhance processing/industrial utilization to improve the output of enset value-added products;
• Sustaining the conservation of the soil to minimize land degradation based on environmentally sound farming practices;
• Integration of EFS production sub-systems (such as cereals, vegetables, fruits, stimulant crops, spices and livestock production) and to enhance the recycling of organic renewable resources for sustaining and conservation of the fertility of the soil;
• Improve the productivity of EFS to increase food and fiber production, and also to create economic synergy among its sub-systems of production;
• Avoid fragmentation of enset traditional farms due to increase of farm families, by introducing favorable land policy that could increase size of enset agriculture to comply with population growth;
• Strengthen the regional and national campaigns to effectively eradicate bacterial wilt and other diseases that threaten EFS.

Challenges for collaborating researchers and scientific institutions

Among the key challenges for collaborating researchers and development institutions/organizations for improving production and productivity of enset crop include:

• Systematic/ scientific classification of enset clones based on botanical characteristics, agronomic and horticultural traits, instead of vernacular names;
• Based on agronomic and horticultural traits and yield performance to register, name and release cultivars/or varieties along the guideline provided by Scientific and Technical Committee of Enset;
• To minimize vernacular names to released cultivars unless cleared through above mentioned scientific committee;
• Retain few high yielding cultivars for food and fiber for each major enset growing region in order to expand clones/varietal trials;
• Strengthen mechanical engineering research for radical improvement of enset processing implements/devices/ machines as well as to develop marketable fermentation vats/containers; and
• Improve the fermentation process by also advancing microbiological research in collaboration with universities and other stakeholders.

The Need for Enset Research Expansion and Growth

During the last two decades (1990 – to present), there has been considerable expansion and growth on enset research partially due to:

• Concurrent institutional development of Southern Region of Agricultural Research Institute (SRARI) and the Areka Agricultural Research Center (AARC);
• New generation of scientists/researchers engaged on various aspects of enset research and development;
• The establishment of botanical collection of several clones of enset from major enset growing regions at AARC (Annex 2) led to an extensive agronomic evaluation with major emphasis on varietal development to improve the yield of food and fiber and to screen resistant cultivars to bacterial wilt diseases as well as to control other diseases and pests.

Agronomic/horticultural research potential

Similar to other root and tuber crops, enset is largely cultivated from 1500-2850 meters altitude where 700-1200mm rainfall and 16-26 degrees centigrade temperature prevail (Table 1). Systematic farm level survey is required to quantify the area of cultivation occupied by the crop. The establishment of Areka Agricultural Research Center (AARC) gave new impetus and thrust on enset
research. The AARC botanical collection of large number of clones/or land races from major enset growing regions advanced agronomic and disease resistance research evaluations in order to identify or develop high yielding food and fiber clones/cultivars.

Atnafua and Endale, 2008, reported the following encouraging research outputs (particularly at AARC). These include:

- Grouping of the enset clones/land races (based on growth cycle, yield of kocho and fiber):
  - **Early Set**: reported superior clones with the highest kocho yield ranging from 310 to 600 qha⁻¹yr⁻¹ and bulla yield from 30 to 60 qha⁻¹yr⁻¹.
  - **The Intermediate Set**: identified 6 clones that gave kocho yield from 350 to 510 qha⁻¹yr⁻¹; also reported 5 clones that gave bulla yield from 31 to 45 qha⁻¹yr⁻¹.
  - **Late Set**: It is likely this group of enset clones mature 2 to 3 years later than earliest set. Reported kocho yield varied from 200 to 350 qha⁻¹yr⁻¹ and reported bulla yield varied from 15-23 qha⁻¹yr⁻¹.

- Selecting high yielding of kocho clones (14); bulla clones (6) and relatively fiber clones (7). This research finding is equally important to expand the cultivation of superior enset clones identified for food and fiber production.

- The above sources of research findings also indicated the best fiber and bulla yielder have been obtained from early set of enset clones;

- The above study also showed that clones that gave high yield of kocho were also observed as good yielders of fiber.

The research progress made to group enset clones based on maturity, yield of kocho, fiber and bulla could save considerable time and resources in the agronomic evaluation to a great extent, and to identify genetic variation among clones to some extent.

**The likely threats to enset agriculture**

The incidence of bacterial disease has threatened enset agriculture to a great extent (Yirgou et al., 1968 and Ashagari, 1980). Fungus diseases such as *Fusarium oxysporum* which threatened enset agriculture in the 1970’s has been the major occupation of research. Fortunately, farm level awareness of the disease lessened the threat of this disease on the cultivation of the crop. The AARC current research activities of pests have focused on key diseases (bacterial wilt, virus and fungus) and other pests (insects and nematodes). This research effort should be further strengthened by availing high level and appropriate lab equipment.

To develop some enset clones resistant to bacterial wilt and other diseases, there is a need to broaden the genetic base of the genus by establishing world collection of about 20 known spp (Cheesman 1947) Annex 1.
It is apparent that the research work at AARC has made progress to screen enset cultivars resistant to bacterial wilt and other diseases based on the evaluation of germplasm collected from major growing areas of the crop as well as using botanical seedlings. In due course, such research thrust could avail to farmers resistant cultivars to bacterial wilt and other diseases.

The second threat to enset agriculture has been in densely populated areas (for example Wolaita, Gamo, Kembata about 300 people/square km), that contributed to the increase of members of farm families, which further contributed to the fragmentation of traditional farms.

An alternative short-pathway to control bacterial wilt disease is to implement a Disease Eradication Campaign recently revitalized and endorsed during the workshop (which involves farmers, extension workers, researchers, and district administrators).

**Biotechnology research**

Selection and agronomic evaluation of elite clones for food and fiber yield has progressed at Areka Agricultural Research Center (AARC). The research work has become complex process due to the occurrence of genome size variation similar to enset’s relative genus *Musa* diploids in which DNA markers can be employed to identify clones resistant to bacterial wilt. The molecular characterization research work started by Almaz (2008) is good beginning to streamline the genetic relationship and variation among *Ensete ventricosum* clones in the identification of genes for resistance to bacterial wilt. Equally important research undertaking on the genus not only the collection and establishment of about 20 spp. of *Ensete* from Africa and Asian countries in addition to *ventricosum* clones; but also to collect and establish selected botanical seedlings in order to broaden the genetic base essential for screening and transferring genes identified for resistance to bacterial wilt and other diseases. Inter-genus and spp. gene transfer employing micro-organisms could also be pursued.

It must be noted that tissue culture research work by itself should not be taken as the only success in bio-technology research, but as modality of propagation of high yielding disease resistant cultivars being pursued to increase large number of enset plants both at Areka and Holleta research centers. This research work and the employment of DNA markers should be supported (fund and facilities) to strengthen biotechnology research on the genus *Ensete* to enhance the identification of genes resistant to bacterial wilt and other diseases, but also to establish the genetic variability among high food and fiber yielding clones. Although agronomic/horticultural research has identified superior enset clones for food and fiber production, their genetic variability and effects will also need to be studied.
Table 1. Climatic adaptation of major root, tuber and corm crops in Ethiopia

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common name</th>
<th>Altitude (M)</th>
<th>Annual rainfall (mm)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ensete ventricosum</td>
<td>Enset</td>
<td>1500—2850</td>
<td>700-1200</td>
<td>16-26</td>
</tr>
<tr>
<td>Solanum tuberosum</td>
<td>Irish Potato</td>
<td>1450-2400</td>
<td>600-1200</td>
<td>16-24</td>
</tr>
<tr>
<td>Ipomoea batatas</td>
<td>Sweet Potato</td>
<td>1400-2000</td>
<td>550-800</td>
<td>18-27</td>
</tr>
<tr>
<td>Colocasia esculenta</td>
<td>Taro</td>
<td>1400-1900</td>
<td>600-850</td>
<td>20-27</td>
</tr>
<tr>
<td>Dioscorea abyssinica (and D. ulbifera)</td>
<td>Yam</td>
<td>1300-1900</td>
<td>500-800</td>
<td>22-27</td>
</tr>
<tr>
<td>Coccinia abyssinica</td>
<td>'Anchote'</td>
<td>1500-2000</td>
<td>700-1200</td>
<td>20-25</td>
</tr>
</tbody>
</table>

Source: Westphal 1975 and Taye Bezuneh 1996

Bio-dynamics of Enset Cultivation

In pursuit of improving the livelihood of millions of people along various agro-ecologies, the EFS, more than any other crop, has evolved environment friendly agricultural practices based on the recycling of renewable resources and economic complementary among its sub-systems of production (i.e. cereals, livestock, fruits, vegetables, stimulant crops, and spices) as discussed below. The EFS is among the backbone of Ethiopian agricultural economy taking into account the following salient analysis.

- **Food security and livelihood perspectives:**
  - The livelihoods for 16-18% of the Ethiopian population in food security and income generation depend on EFS;
  - Regions where enset is used as major or co-staple food are among the most densely populated in Ethiopia, as already mentioned in the introduction part;
  - It has been established that only 15 to 25 enset plants could provide the yearly supply of food per person;

- **From socio-cultural diversification perspectives:** as basic or co-staple diet for millions of people of different ethnic groups, the EFS has influenced the development of rich and diversified cultures.

- **The EFS has integrated the cultivation of cereals, root, tuber, stimulant crops, spices and even livestock production to sustain both livelihoods and income generation.**

- **The EFS is economically more viable and durable farming practice and it has already integrated conservation of soil fertility through the use of manure, cereal/legume rotation, and crop residue input into the soil and**

- **The EFS bio-dynamism has incorporated diversified cropping systems along various agro-ecological zones (Westphal 1975 and Stanley 1965), which enabled 6-12 harvests for cereals; 4 to 8 harvest for cotton; 1 to 3 harvests for fruits; 8 to 12 harvests for vegetables; 3 to 5 harvests, for papaya; 4 to 5 harvests for established coffee or one harvest for newly established coffee; orchards before the completion of the growth cycle of the enset plant (i.e. harvesting), and**

- **Bi-Yearly production of large animals such as dairy and beef and yearly production of small animals such as poultry, sheep etc.**
Food Production and Nutritional Value

Food production potential

Over the last three decades, the total area covered with the enset crop has grown from 65,000 ha (Stanley 1965) to about 300,000 ha (CSO 2009/2010). The Southern and Oromia Regions produce close to 80% of the crop. The kocho and bulla yield of enset clones seem to vary considerably. Table 2 compares the yield of four clones previously studied that gave yield at the level of 190 to 3000 q/ha·yr⁻¹ kocho and less than 30 q/ha·yr⁻¹ bulla (Taye Bezuneh 1966/1973/84). Since the establishment of AARC several superior food and fiber yielding cultivars (such as Digomerza, Godera, Henuwa and Zerbo) that gave yield over 430 q/ha·yr⁻¹ kocho and at least 40 q/ha·yr⁻¹ bulla were identified (Atnafua and Endale, 2008). Systematic planting or intercropping of these new cultivars at their respective agro-ecologies, and concurrent improvement of enset harvesting and processing implements/devices could easily triple the volume of enset production.

Enset propagation practices and its planting system (involving traditional stages of nurseries) have been reviewed extensively (Mulugetta et al. 1996/2008). Series of enset propagation studies including tissue culture have established the pathway for rapid and large scale multiplication of enset planting materials (Mulugetta et al. 2002/2003) that should be explored.

Table 2. Kocho, bulla and fiber production of some enset clones

<table>
<thead>
<tr>
<th>Vernacular Names</th>
<th>Kocho (q/ha·yr⁻¹)</th>
<th>Bulla (q/ha·yr⁻¹)</th>
<th>Fiber (q/ha·yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferezae +</td>
<td>247</td>
<td>33</td>
<td>389</td>
</tr>
<tr>
<td>Ado +</td>
<td>192</td>
<td>29</td>
<td>460</td>
</tr>
<tr>
<td>Midasho +</td>
<td>304</td>
<td>27</td>
<td>559</td>
</tr>
<tr>
<td>Tuzuma +</td>
<td>386</td>
<td>26</td>
<td>380</td>
</tr>
<tr>
<td>Henuwa</td>
<td>440</td>
<td>43</td>
<td>317</td>
</tr>
<tr>
<td>Godera ++</td>
<td>520</td>
<td>NA</td>
<td>424</td>
</tr>
<tr>
<td>Zerbo ++</td>
<td>420</td>
<td>47</td>
<td>362</td>
</tr>
<tr>
<td>Digomerza ++</td>
<td>550</td>
<td>57</td>
<td>406</td>
</tr>
<tr>
<td>Gena ++</td>
<td>410</td>
<td>NA</td>
<td>554</td>
</tr>
</tbody>
</table>

Sources: Taye Bezuneh 1973/84 for + and Atnafua Bekele et al. 2008 for ++
NA = Not available

Nutritional value

Table 3 summarizes the nutrient value of enset (ENI, 1981). The result of the study shows that the carbohydrate content that of bulla is much higher and its protein and calcium much lower than kocho. Previous studies indicated that the carbohydrate content of the clones evaluated, such as Ferezae, Ado and Tuzuma therefore, varied from 178 qt/ha to 293qt/ha/ (Taye, 1984). Accordingly, the energy yield of enset is estimated from 140,000 to 220,000 kilo joule /ha (ENI 1981). However, the processing of kocho to bulla reduces the calcium content to 65 mg/100 gm and concurrently
raises the carbohydrate content of *bulla* to 54.4% per 100 gms from 41.3% (Table 3). The traditional belief that using special enset cultivars for food preparation can help to heal fractured bones seem to have some validity, since the calcium content of enset food is comparatively higher than most cereals.

The 1990's extensive survey on vitamin A deficiency (which causes night blindness) that involved on more than 6600 children covered four ecological zones including enset cultivated area. The surprising finding of the survey has been that the overall diet of the enset zone has the highest concentration of beta-carotene or vitamin A source that prevents night blindness. This national survey findings led to recommendation for vitamin A deficiency control program throughout the country, except or outside the enset zone (ENI Survey referred in Lost Crops of Africa: Volume LI, pp 179-1802). This has been attributed to vegetable gardens usually affiliated with EFS and its leaf-sheath fresh leaves cooked for consumption.

Table 3. Nutrient composition of two ensete flour products (percent per 100 g dry weight)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Kocho</th>
<th>Bulla</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>56.3%</td>
<td>45.25%</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>41.3%</td>
<td>54.40%</td>
</tr>
<tr>
<td>Protein</td>
<td>1.2 (3.35)</td>
<td>0.25</td>
</tr>
<tr>
<td>Fat</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Iron</td>
<td>5.3 mg/100 g</td>
<td>7.7 mg/100 g</td>
</tr>
<tr>
<td>Calcium</td>
<td>195 mg/100 g</td>
<td>65 mg/100 g</td>
</tr>
<tr>
<td>Thiamin</td>
<td>Mg/100 g</td>
<td>0.03</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>Mg/100 g</td>
<td>0.04</td>
</tr>
<tr>
<td>Niacin</td>
<td>Mg/100 g</td>
<td>0.025</td>
</tr>
</tbody>
</table>

Source: Ethiopian Nutrition Institute 1981

Enset food contains from 1.72 % to 6.2% protein, with mean value of 3.35% after two months of fermentation (Table 4). In general, enset food of fermented pulp has relatively higher lysine than most cereals. However, methionine and iso-lucine are the first and second most deficient essential amino acids, respectively (EFS, 1981). The quality of protein of *kocho* improves with length of fermentation. The effect of length of fermentation on protein content of kocho food is summarized below.

- Protein content changed from 3.60% before fermentation to 3.35% after fermentation;
- The length of fermentation improves the quality of protein as determined by amino acid profiles;
- The food or *kocho* protein becomes generally higher in lysine than most cereals; and
- The food or its diet contain high calcium content that accrued in traditional treatment/ claims of healing fractured bones (Fig. 1)
Ensete ventricosum clones and Finger Millet (also known as Dagussa vernacular name in Amharic) are important sources of calcium compared to other staple cereals such as teff, wheat and maize (Fig. 1, synthesized data, 1981).

Table 4. The effect of length of fermentation on protein content of kocho

<table>
<thead>
<tr>
<th>Fermentation period</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>1.72</td>
<td>6.00</td>
<td>3.68</td>
</tr>
<tr>
<td>1 month</td>
<td>1.69</td>
<td>4.69</td>
<td>3.35</td>
</tr>
<tr>
<td>4.5 months</td>
<td>1.88</td>
<td>4.44</td>
<td>3.24</td>
</tr>
<tr>
<td>5.5 months</td>
<td>1.91</td>
<td>4.25</td>
<td>3.10</td>
</tr>
</tbody>
</table>

Source: Abrham Besrat et al. 1979

/Ca mg 100⁻¹ g

Fig.1. The calcium content of some food crops in Ethiopia
Source: Taye Bezuneh (Synthesized data 2010)
Agro-processing/value-added products

- Fiber production for industrial use

Data on enset fiber production in general and its yield per unit of land is virtually lacking. The fiber yield of some enset clones varies from 3.8 to 5.9 quintals/ha (Table 2). Over the last two decades, enset research has advanced in the identification of high food and fiber yielding enset cultivars. In case of fiber yield, since 1973 Ado, and Midasho gave yield of 4.60 and 5.59 qha\(^{-1}\)yr\(^{-1}\). Likewise, Gena and Godera also gave fiber yield from 4 to 5.5 qh\(^{-1}\)ay\(^{-1}\) (Atnafua et al. 2008).

Enset and abaca fibers have similar strength and quality standard as summarized in Annex 3. The Philippines in particular used the abaca (*Musa textilis*) fiber to expand its manufactured industrial product that also attracted export markets to Europe, North America and other countries.

Despite the research findings (four decades ago) the enset fiber is of high quality and similar standard to that of abaca fiber. However, very limited industrial manufacturing did take place in Ethiopia due to lack of innovations by both the public and private sectors.

- The rationale and challenge

Enset agriculture being the livelihood of 16 to 18% of Ethiopian population, its cultivation is well established for several decades at various agro-ecologies. As major and co-staple food, the crop also provides fiber/starch/paste which can be transformed for manufacturing several products. It is estimated that about 60,000,000 kg fibers is imported yearly into Ethiopia for industrial uses. The local supply of enset fiber is estimated about 15,000,000 kg. The lessons/experiences of Ethiopia’s industrial growth show too much dependence on foreign investors which has been slow and least productive. This scenario can be improved by:

- Creating enabling environment (land access and fund, loans) and organizing cooperatives comprised of young generation including college graduates in the major areas of enset cultivation;
- Supporting industrial level of enset production, for example, cooperatives in major enset growing areas may have members above 500 with at least 3 ha of land available to each member;
- Expanding the production of newly identified high fiber yielding enset clones by respective cooperatives and large scale private sectors producers;
- Attracting private investors to establish the fiber and starch/paste industries;
- Organizing the cooperatives as out-growers to supply enset fiber raw material to the manufacturing industries; and
- Establish Eco-Tourism micro-industries at the most sub-urban centers and villages.

Industrial growth of this nature could be the basis for establishing the Eco-Tourism oriented fiber and food processing micro-industries at most attractive sites.
throughout enset growing regions (i.e. Woliso, Wolekitie, Endibir, Awassa, Yirgalem, Dilla, Welaita Sodo, parts of Oromia Region etc). These Eco-Tourism oriented micro-industries can manufacture enset fiber based products, and also generate income from sales of products, as well as from visits of sites by tourists.

Based on the above mentioned enabling policy, to organize cooperatives and also support the private sector involvement, Ethiopia in due course must export manufactured products including those listed below similar to what the Philippines did to all continents over the last five decades.

- **Manufacturing products**
  Banana and enset fibers have high tensile strength, light weight, and good moisture absorption. These fibers have insulating, thermal conductivity, biodegradable characteristics. Similar to abaca, enset fiber can be used for manufacturing the following products: Bags of all sorts including ladies bags; paper making; starches, paste for textile and other industries; car seats, cushion and pillows; coats and jackets of various quality and sizes; shirts, dresses, trousers and hats; mats of various sorts and sizes; home furniture and folding dividers, dining sets, hanging shades; chairs, beds, tables; twines, cordages and lamp shades; carpets of various sorts; hand woven rugs; making garments; curtains of different colors; jewelry of various designs; suit cases of various sorts; roof insulations and tiles if further processed and integrated with tiles; shower & bath unit through further processing and integration with other fibers; making handicrafts and home decorative; wide variety of applications in making various products like paper bags, filter paper, greeting cards, decorative papers, pen stands and many more. These products have potential markets and hence concerted efforts should focus in the development of elite clones for the development high quality fiber.

- **The development of appropriate harvesting and processing technologies**
  Food and fiber extraction from the crop has always been poor both qualitatively and quantitatively. Research should also focus to substantially improve harvesting and processing machines/or equipment to increase outputs of both food and fiber as well as to concurrently relief women from such tedious and cumbersome labor. Annex 4 summarizes some of the progresses made and the need for further improvement required on enset harvesting and processing implements/devices. However, the decorticating of enset pseudo-stem, pulp and the pulverization of corm require the following changes that:
  - The nature of enset harvesting, decortications of the pseudo-stem and leaf-sheath require more power (energy or machine) and change of size of the implement;
  - The design should focus on mechanization that could lead to industrial use of enset food and fiber products at community level or by investors who could afford to buy improved devices / or equipment use with motors;
  - Strengthening mechanical engineering and food technology researches be considered crucial;
Thus, the improvement of harvesting and processing implements/devices require the concurrent research in mechanical engineering and food science technologies; concerted effort should be exerted to further improve the decorticators that separates pulp from leaf-sheath; pulverizer that grates the corm into fine pieces; shredder that chips the fiber in the fermented kocho; and kneader to squeeze out water from fermented kocho.

- **Standardization of the fermentation process**
  The fermentation process of enset food can be standardized to substantially increase the recovery of fresh weight by at least 50% to fermented and dried products. Such an increase of recovery will improve the volume of the production of kocho and bulla. Atrafina et al. (2008) did undertake extensive trials tostandardize quality fermentation using different types of vats including plastic material. Kocho stored in the traditional way practiced by farmers apparently gave the highest quality both in texture and color compared to all other storage after 10 months of fermentation period. The study also showed kocho stored in plastic materials also sustained better quality. However, it is advisable not to use plastic material based on recent findings that warrant leakages of chemicals from plastic is hazardous to health.

Microbiological and biochemical studies of the fermentation process such as time-interval studies of the chemical change could identify the kind of micro flora or organisms associated with fermentation of enset foods, and also standardize the process. Food science and technology research is necessary to make enset processing hygienic and systematic. There is also role for microbiologists to identify the micro organism by creating pure cultures to produce quality and standardized kocho.

Agricultural and mechanical engineers and food technologists will need to be provided with financial support and equipment/implements that will substantially improve the fermentation containments and process. Microbiologists also require modern facilities, and financial support to identify useful microorganisms to improve quality of the fermented product and to standardize the process.

- **Outputs of enset food processing**
  These include: Flour for preparing bulla; kocho for preparing bread and different foods, porridge and dumplings; amitcho (starch cooked like potato); corm grated or cut into pieces for preparing various foods; starch/paste useful for cloth and book binding, textile, leather, food, garment finishing, and printing industries.
Recommendation

The way forward for modernizing enset production and expanding its economy

- **Modernizing enset production**
  Although the EFS has sustained food security, there is a need to expand its economy by modernizing its planting system and the integrated development of the fiber and food processing industries. Modernizing EFS could be done through:
  - Creating more jobs to young generation of farmers including college graduates;
  - Minimizing fragmentation of traditional EFS due to increased farm family size
  - Expanding the EFS economy

- **Improving the available technologies for expanding the Enset Economy**
  include:
  - Promote high yielding food and fiber clones
  - Develop industries that will utilize enset fiber in large scale for both export and domestic markets;
  - Sustain the highly developed Farming System to support the livelihood of 16 to 18% of Ethiopian population; and
  - Strengthen the EFS, which has evolved environment friendly agricultural practices based on the recycling of renewable resources and economic complementarities among its sub-systems of production (i.e. crops, livestock, fruits, vegetables, stimulant crops, and spices)

- **Some Pertinent Hints for the Development of Economically Viable Enset Farming System:**
  Certain important components to modernize EFS planning at major enset growing regions are to:
  - Put in place favorable land use practice to sustain productive EFS.
  - Organize member of the new generation of farmers cooperatives with members who systematically inter-crop enset and coffee for improving production and productivity in order to triple food and fiber production and increase income by several folds from the interplant cash crop; and
  - Systematically intercrop the enset plant (600 plants/ha) for food/fiber; and coffee as cash crop (400 plants/ha).

Collectively, these cooperatives could serve as important source of fiber for the industry as well as to expand Eco-Tourism oriented micro-industries. At mid altitude
1500 to 2000m above sea level optimum yield for both Enset and Coffee is likely to be obtained.

- **Modernizing enset food and fiber harvesting and processing**

  To further upgrade slightly improved enset harvesting and processing implements, survey at farm and research levels is necessary particularly to:

  a. Assess the technological fitness and acceptance of improved and previously distributed devices;
  
  b. Further improve food and fiber processing implements or devices based on previous experiences/lessons, and
  
  c. Involve the private sector and youth engineers to manufacture and market improved enset extraction devices.

- **Eco-Tourism oriented fiber and food processing micro-industries**

  In many respects, the growth of manufacturing industry in Ethiopia has been slow compared to several other countries. The typical case has been the expansion of abaca manufacturing industry over 50 years ago in the Philippines compared to that of enset fiber industry in Ethiopia during the same period. The high standard quality of enset fiber (similar to abaca) has been determined since the last four decades (Taye 1963/73), its industrial potential has yet to be fully explored in Ethiopia (Annex 3).

  The modern cooperatives mentioned above if expanded throughout the enset growing regions could serve as an important source of raw material for fiber and food processing industries. Through industrial innovation, the enset fiber could also blend with fibers of other crops such as flax, cotton, ramie, bamboo fiber, to manufacture clothes such as dresses, jackets, coats, shirts, hats, light shoes, car seats, cushion, pillows etc.

  Modernization of enset fermentation process could also enhance the processing of *kocho* and *bulla* to be further processed into several food byproducts.
Annex 1.

Major spp. of the genus Ensete

- **Ensete gilletti** is largely adapted in drier areas in West and Central Africa from Sierra Leone, Nigeria, Cameroon, to Angola;
- **Ensete perrieri** is largely distributed on the island of Madagascar;
- Most species of Ensete are widely distributed across Africa except for **Ensete glaucum** and **E. superbium** which are of Asian origin;
- **Ensete calospermum** is widely distributed in the Pacific, Fiji and in New Guinea;
- **E. facundum** and **bagshawei** largely distributed in Eastern Africa including in Uganda;
- **Ensete amoldianum** largely distributed in tropical Africa;
- **Ensete schweinfuthii** distributed in Sudan;
- **Ensete ruandense** adapted in most warm climates originally observed in Rwenzori;
- **Ensete rubronenvalum** adapted in Rwanda, Congo and Rwenzori.
- **Ensete wilsoni** distributed in southern China;
- **Ensete buchanani** mostly distributed in the highlands of Southern Africa;
- **Ensete davya**e largely distributed in Mozambique;

Source: Chesman EE 1947 Classification of the bananas, I The genus Ensete Horan Kew Bulletin No 2

Annex 2

The Extent of Number of "Enset or Isset" Clones referred in major growing regions of the crop.

<table>
<thead>
<tr>
<th>Area</th>
<th>Number of clones referred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sidama</td>
<td>97</td>
</tr>
<tr>
<td>Gedio</td>
<td>42</td>
</tr>
<tr>
<td>Wolaita</td>
<td>77</td>
</tr>
<tr>
<td>GamoGofa</td>
<td>196</td>
</tr>
<tr>
<td>Kembata</td>
<td>142</td>
</tr>
<tr>
<td>Guraghe</td>
<td>70</td>
</tr>
<tr>
<td>Borena</td>
<td>28</td>
</tr>
</tbody>
</table>

Source: Atnafua Bekele et al., 2008. Published in Root and Tuber Crops page 157
Annex 3
Comparative tensile strength and relative quality of some commercial fiber crops

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Type of fiber</th>
<th>Fiber strength (gms per denier)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Musa textalis</em></td>
<td>Abacca</td>
<td>7.0</td>
<td>Fiber of high quality and standard, manufactured extensively to produce ropes, mats of various sorts, lady bags, jackets, car seats etc. These products have attracted export markets to North America, Europe, Middle East countries etc.</td>
</tr>
<tr>
<td><em>Ensete ventricosum</em></td>
<td>Enset</td>
<td>5.0</td>
<td>Fiber of high quality and standard, the last four decades in Ethiopia, industrial manufacturing not expanded due to limited innovations by both public and private sectors</td>
</tr>
<tr>
<td><em>Agave sisalana</em></td>
<td>Sisal</td>
<td>4.4</td>
<td>Fiber strong and durable and industrially manufactured</td>
</tr>
<tr>
<td><em>Sansevieria spp</em></td>
<td>Sansevieria</td>
<td>4.5</td>
<td>Same as above</td>
</tr>
<tr>
<td><em>Agave spp</em></td>
<td>Henequen</td>
<td>3.3</td>
<td>Same as above</td>
</tr>
</tbody>
</table>

Source: Taye Bezuneh (1972/73) Debre-Zeit Agricultural Research Center
## Annex 4

Status of the improvement of the enset processing devices implements:

<table>
<thead>
<tr>
<th>Types of implement</th>
<th>Extraction part</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>a). Scrapper or decorticator</td>
<td>Pseudo-stem and leaf-sheath</td>
<td>Improvement of the traditional implement started in 1970. The Rural Technology Promotion Center distributed 180 of the scrapers to Enset growing areas (Guraghea, Awassa, Sidama, Kambata, North Omo, and Areka). The improved decorticator or scrapper however required more force and it is also time consuming with the improved scrapper or decorticator 48kg/hr of the enset pseudo-leaf-sheath has been extracted compared to 33Kg/hr with traditional implement.</td>
</tr>
<tr>
<td>b). Kneader or Water</td>
<td>Thirty-two of water squeezing</td>
<td>Thirty-two of water squeezing devices which almost removed unwanted water from enset food were distributed to Guragea zone, Kambala and North Omo. Improved implement relatively hygienic, can be operated by men also and can squeeze up to 110 Kg/hr compared to 70 Kg/hr with traditional implements</td>
</tr>
<tr>
<td>Pressing or Squeezing</td>
<td>Device</td>
<td>c) Pulverizer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d) Shredder</td>
</tr>
</tbody>
</table>

Source: Deribe Kifle 1996
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Past Research Achievement and Existing Gaps on Enset (*Ensete ventricosum* (welw.) Cheesman) Breeding

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Abstract

Enset (*Ensete ventricosum* (Welw.) Chessman) is a perennial, herbaceous and monocarpic crop belonging to the family Musaceae (Westphal 1975). Enset based farming system is an indigenous and sustainable agricultural system in Ethiopia, and the crop is highly related with sustainable agriculture and food security, and thus to the economic, cultural and social life of different ethnic groups. Despite, the many uses of enset which make the crop to be highly related to sustainable agriculture, there are a lot of biotic and abiotic factors still existing threatening its production and productivity. In the past various research activities have been conducted to generate new production technologies and to promote them to the end users. Many of the researches on enset have been concentrated on agronomic studies. Concerning issues in relation to disease management options, only few research findings on pathogen survival, means of dissemination, pathogenicity test, sanitary control, and identification of some tolerant clones and enset root mealy bug control measures were conducted. On the genetic improvement of enset only some limited works were conducted so far: attempts were made to collect and preserve all the possible enset germplasms in the country and currently, a total of 623 enset germplasms from 12 major enset growing areas of Ethiopia have been collected and conserved ex situ by the Southern Agricultural Research Institute of Areka Agricultural Research Center. The other breeding research finding was the Morphological characterization of enset clones based on phenotypic, quantitative and qualitative traits has been done at Areka Agricultural Research Centre which considered the majority of enset accessions from the six major enset growing areas of Southern region of Ethiopia. The result of the diversity index showed that low levels of diversity existed among the 279 *Enset ventricosum* accessions based on the frequency of the phenotypic characters considered. Attempts were also made to develop regression model which, non-destructively, predicts yield of enset with better precision and simplifying yield evaluation in experiments and also solve difficulties in estimating kocho yield in the assessment of production balance in enset production region of the country. The experiment was carried out at Areka Agricultural Research Center’s on-station site on a total number of 328 enset plants from the six major enset growing areas of Southern Ethiopia. Plant height and pseudostem circumference were found to be the best non-destructive enset kocho yield predictors with R-square (0.78) value for estimating fermented squeezed kocho yield with the model equation of $\text{FUNK} = -25.76 + 5.35\text{PH} + 20.01\text{PSC}$ describing the relationship of fermented un-squeezed kocho as a function of enset plant height and pseudostem circumference measurements. The other achievement which has a paramount contribution in enset research and development was the development of enset varieties for best quality and yield of kocho which was conducted on
a total of about 400 enset accessions collected from the major enset growing zones (Kembata, Daoro, Gamo-Gofa, Wolaita, Sidama and Gurage) of SNNP Region of Ethiopia. The experiment resulted in the identification and release of six enset varieties, namely Yanbule, Geioada and Endale from early maturing (3 to 4 years) and Kelisa, Zerita and Mesena from late maturing (4 to 5 years). Future breeding researches should also focus on undertaking further work in exploiting the previously untraced enset growing areas of the country to collect all the possible enset accessions and preserve them for future use and to guarantee and ensure the availability of these resources in the future with back up support of in vitro (cryopreservation and slow growth) techniques. Development of a well established taxonomic classification and descriptor list and undertaking molecular characterization of all the available enset clones using recent molecular techniques should also be given due emphasis. In addition, more new enset varieties with merits of good culinary qualities and disease resistance especially to bacterial wilt of enset should be developed through cross breeding, mutation and genetic engineering to achieve food security and ensure sustainability.

Introduction

Enset (Ensete ventricosum (Welw.) Chessman is a perennial, herbaceous and monocarpic crop belonging to the family Musaceae (Westphal 1975). It is a large plant with a height usually grown about 3-8 m. The pseudostem (false stem), which consists of a system of tightly or loose clasping and lax overlapping leaf-sheaths, dilated at the base and having circumference and height ranges of 0.55-2.27m and 0.7-3.6 m, respectively. The length and width of matured leaf are in the range of 0.7-4.82 m and 0.17-0.97 m, respectively (Yeshitila and Diro, 2009a).

Enset corm is typically, stout tuberous or fleshy with conically growing structure. It bears lateral and apical buds at the centre of the junction of corm and pseudostem. Corm is also the source of kochio and it is also used as fermenting agent or starter. Corm weight of matured (flowered) enset plant after grated was in the range of 12.5-75.0 kg/plant. Botanically true stem remain short at the base of central shoot at vegetative stage. When plant enters generative stage the true stem grows fast. At maturity the true stem bears peduncle and inflorescence at the top, which are pendulous. Enset flowers are many to each bracts in two rows, those at the lower inflorescence are mostly female, the middle are hermaphrodite and while the upper inflorescence are male. The fruits of enset are dry and leathery except their size the fruits resemble banana fruits. Enset produces hard and blackish seeds (Tabogie, 1997).

There are six commonly recognized species of Ensete, E. superbuni and E. glaucum grow wild in Asia, E. perrieri in Madagascar and E. gilletii, E. homblei and E. ventricosum in eastern Africa (Simmonds, 1962). Some species of Ensete are also reported to grow in North America (Chessman, 1947). Ensete ventricosum is considered to be the only wild species growing in Ethiopia (Simmons, 1956). Ensete ventricosum was previously cultivated only in the south and south-western parts of
Ethiopia but the recurrent droughts have led to the expansion of enset cultivation to other parts of the country (Birmeta, 2004). The optimal conditions for enset cultivation occur at 2000–2750 m with 1100–1500 mm rainfall, a temperature range of 10–21 °C and a relative humidity of 63–80% (Brandt et al., 1997). Enset often grows best in acidic, heavy clay soils that retain high levels of organic matter when manured (Shank, 1994).

Enset cultivation is concentrated in the highlands of south and south-western Ethiopia covering approximately 168,000 ha and is the staple and co-staple food source for about 10 million people (CSA, 1997). Productivity of the crop is also very high compared to other crops but varies depending on edaphic factors, altitude, cultural practices and varietal differences (Birmeta, 2004). Actual fresh kocho yield of enset reported by CSA (1997) was 28.01 and 25.93 kg/plant in Oromia and SNNP regions, respectively. From these figures the national average actual “kocho” yield in tons ha\(^{-1}\) year\(^{-1}\) was found out to be 11.87, assuming a growth period of 4.5 years and plant population of 2222 enset stands per hectare in farmers’ fields. Bezuneh (1984) also reported the average national average “kocho” yield to be between 7.41 and 11.95 tons ha\(^{-1}\) year\(^{-1}\) assuming 2000 plants/hectare. Based on the CSA (2009) the total area under enset production in Ethiopia is 278667.5 ha with annual total kocho yield production of 5565898.5 qt from these figures the national average actual “kocho” yield was found out to be about 2.0 tons ha\(^{-1}\) year\(^{-1}\). Fresh yield potential of “kocho” may go up to 150 tons ha\(^{-1}\) year\(^{-1}\) assuming growth period of 3 years and plant population of 2500 enset plants per hectare (calculated from total dry biomass which is 30% of the total fresh total biomass with harvest index of 0.5) (Tsegaye, 2002).

Enset is a multipurpose crop with all plant parts being utilized for human food, animal forage, medicinal or ornamental uses (Pijls et al., 1994). It has high significance in day-to-day-life of the peasant households cultivating this crop as staple food (Bezuneh, 1983; Brandt et al. 1997). The peasants indicate that enset is their food, their cloth, their house, their bed, their cattle-feed and their plate (Brandt et al., 1997). The types of products obtained from enset are kocho, bulla and amicho, which are used as human food providing mainly carbohydrate and energy. Fibre is the by-product, which according to Bzuneh (1996) is believed to be an excellent structure and its strength was found to be equivalent to important fiber crop Musa textalis and serves as a valuable raw material in local industries. Enset starch is also being used for textile, paper and adhesive industries in saving the foreign exchange (Ethiopian Science and Technology Commission, 2003). Enset also plays an important role as a feed for animals during dry spell when feed is scare. Some of the enset clones are used as local medication for different illness such as bone fracture, bone breakage, diarrhoea, in discharging placenta, for both human being and animals (Tsegaye, 1991). It therefore contributes enormously to food availability and economic sustainability.
In Ethiopia enset based farming system is an indigenous and sustainable agricultural system. Due to productivity and tolerance to transient drought, enset is regarded as a priority crop in Ethiopia. The *kocho*, major yield, of enset per unit area and time (in terms of weight and energy) is much higher than the yields of any other crop grown in Ethiopia, and therefore, the cultivation of enset in densely populated areas under low input conditions can sustain the population better than any other crop (Tsegaye, 2002). It has also been known to buffer food deficit during dry spell and recurrent drought because of its resistance to a fluctuating rainfall pattern after establishment.

In case of food shortage enset plant can be harvested at any age of the plant and at any time of the year. Under normal storage condition *kocho* can be stored up to 10 years without being spoiled (Bezuneh, 1983; Alemu and Sandford, 1991; Tabogie, 1997). The corm (*nimicho*) is also cooked and consumed in the same way with other root and tuber crops and it is a source of food during critical food shortage in parts of a year. As a result, enset has tremendously been contributing to food security in the country. The crop represents 65% of the total crop production and the highly carbohydrate rich products serve as staple and co-staple food for about 20% of population of Ethiopia (Brandt *et al.*, 1997; Spring *et al.*, 1996; Alemu and Sandford, 1991).

The plant is also an attractive evergreen ornamental which is being introduced to different geographical regions of Ethiopia. The presence of 20-40 magnificently huge *enset* plants framing small huts and farmyards presents an impressive picture (Shank, 1994).

Enset has very large leaf area and the canopy is closed after plants are established and thus it protects rainfall from splashing the soil; the leaf litter checks runoff and also improves nutrient recycling. According to Elias (1998) soil fertility is being maintained, and even increased, in enset fields. It was also emphasized that erosion does not occur in these fields, because of high organic matter and a more stable soil structure, the presence of mulch material and greater care provided by the farmers. Woldetensay (1997) also reported that higher levels of nutrients are present in enset fields than in non-enset fields. As a result of such multifarious uses of enset makes it highly related with sustainable agriculture and its cultivation is deeply entwined in the economic, cultural and social life of different ethnic groups (Birmeta, 2004).

Despite, the many uses of enset which make the crop to be highly related to sustainable agriculture, there are a lot of biotic and abiotic factors still existing threatening its production and productivity. In the past various research activities have been conducted to generate new production technologies and to promote them to the end users. Many of the researches on enset have been concentrated on agronomic studies (Bezuneh 1996). Agronomic researches were developed mainly by Areka, among which propagation (seed/vegetative), planting time, plant spacing, frequency and rate of organic and inorganic fertilizer application and frequency of transplanting are the major ones (Diro, 1997; Belehu, 1996; Tabogie *et al.*, 1996; Haile
Concerning issues in relation to disease management options, research findings on pathogen survival, means of dissemination, pathogenicity test, sanitary control, and identification of some tolerant clones and enset root mealy bug control measures are among the major ones. On the genetic improvement of enset only some limited works were conducted so far, of which the most important ones are indicated below with their research gaps.

### Previous Research Achievements on Enset Breeding:

#### Collection and Maintenance of Enset Germplasm

Most of the genetic diversity of enset is traditionally maintained *in situ* by farmers (Shigeta, 1991). Unfortunately, many valuable clones have been lost because of various human and environmental factors (Gebremariam, 1996), which may have reduced the total available genetic diversity of the crop. Nowadays, many people have become aware of the importance of preserving genetic diversity for the survival and continuation of any form of life that exists on earth. Data on the relative genetic diversity within and among plant populations can have a major significance in the preservation of genetic diversity in crops and the improvement and maintenance of crop germplasm for sustainable agriculture (Birmeta, 2004).

Attempts were made by researchers of Areka Agricultural Research Center to collect and preserve all the possible enset germplasms in the country and currently, a total of 623 enset germplasms from 12 major enset growing areas of Ethiopia (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) have been collected and conserved *ex situ* by the Southern Agricultural Research Institute of Agricultural Research at Areka (Yeshitila, et al., 2009). According to information obtained from questionnaires being distributed among enset growing areas, the expected number of vernaculars in Sidama, Gedio, wolaita, Jamjem, Gomu-Gofa, west Shewa and kembata Hadya was 97, 42, 37, 28, 106, 70 and 142, respectively. Therefore, further work has to be done in exploiting the previously untraced enset growing areas of the country to collect all the possible enset accessions and preserve them for future use.

A number of enset accessions, which could be used in future crop improvement program for the development of resistant/tolerant to bacterial wilt and other desirable agronomic traits, are maintained in field gene bank at Areka ARC (Yeshitila et al., 2009) and in *situ* by farmers (Gebremariam, 1996). However, these accessions are exposed to biotic and abiotic factors. The clones also need to be rejuvenated on average once per two years to keep them in the maintenance field, which makes the process labour intensive, apart from taking more space and time. Moreover, all enset accession might be infected by currently devastating disease, enset bacterial due to
the motility of the causative agent. In order to ensure the availability of these resources in the future, *in vitro* (cryopreservation and slow growth) conservation backup is important.

**Phenotype and Genotype Base Variability Study of Enset Clones Under Areka Condition**

Most of the earlier research on *enset* has focused on agronomic studies that include yield and productivity, plant density and intercropping (Bezunhe, 1996). Hence, only limited research was conducted on the molecular characterization of *enset* clones of which molecular characterization research conducted by Tsegaye (2002), Negash (2001) and Birmeta (2004) are the major ones. However, only few *enset* accessions from a few *enset* growing area were molecularly characterized in their study. In addition, attempts have been made to document and analyse clonal identity using farmers’ classification. In these cases, clonal names reported in the literature are associated with the limited phenotypic data provided by farmers (Shigeta, 1991).

Morphological characterization of *enset* clones based on phenotypic, quantitative and qualitative traits has been done at Areka Agricultural Research Centre (Tabogie, 1997 and Yeshitila and Diro, 2009b; Yemataw, 2010). However, morphological characterization of the clones is rudimental and a well-established taxonomic classification and descriptor list are lacking. The morphological characterization and evaluation work in the study undertaken by Areka Agricultural Research Center was the first of its kind. It had considered the majority of *enset* accessions from the six major *enset* growing areas of Southern region of Ethiopia. Thus, it is of paramount importance in providing reliable information for future work where duplication of efforts that are creating complications in the conservation, improvement, and utilization of *enset* by farmers, conservationists and breeders would be avoided. In the study two hundred seventy seven accessions of *Enset ventricosum* were tested at Areka Agricultural Research Centre in a non-replicated field. The objectives of the study were to assess the diversity of these accessions based on key morphological descriptors and evaluate the accessions for yield and yield related traits. Data on 6 qualitative and 22 quantitative traits were collected and subjected to various statistical analyses (Gomez and Gomez, 1984). Cluster analysis based on qualitative characters indicated the formation of six clusters and existence of variability on leaf, midrib and petiole traits. The result of Shannon-Weaver diversity index ($H^*$) showed that low levels of diversity existed among the 279 *Enset ventricosum* accessions based on the frequency of the phenotypic characters considered. Analysis of variance for quantitative characters indicated significant variation among the accessions in all the 22 yield and yield components of *enset* plant. The cluster and distance analysis of quantitative characters pointed out the distance between most of the clusters were highly significant ($P < 0.01$) indicating diversity among accessions in the different clusters. Correlation study between various quantitative characters showed highly significant association among characters. Maturity time has a negative correlation
with yield and yield components of an enset plant (Yeshitila and Diro, 2009b; Yemataw, 2010).

However, morphological characterization of the clones is rudimental and a well-established taxonomic classification and descriptor list are still lacking. Few attempts have also been made to document and analyze clonal identity using farmers’ classification. In these cases, clonal names reported in the literature are associated with only limited phenotypic data provided by farmers (Shigeta, 1991). Although assessment of morphological variation present in enset is feasible, rather its use is limited due to the small number of phenotypic markers and the fact that they are influenced by environmental conditions. Molecular characterization of enset clones was conducted using AFLP (Tsegaye 2002; Negash 2001) and RAPD techniques (Birmeta, 2004). However, enset accessions form limited enset growing areas were considered in their studies. In the future, the development of molecular markers and marker assisted selection methods for improved characterization of the different Enset accessions collected from all the major enset growing areas of the country, employing few of the different types of molecular markers that have been applied on Musa, such as: RFLP, AFLP based on PCR amplification of selected restriction fragments and microsatellites would have a paramount importance for future advancement of enset research.

Development of Enset Yield Estimation Models

Attempts were also made to develop regression model which, non-destructively, predicts yield of enset with better precision and simplifying yield evaluation in experiments and also solve difficulties in estimating kocho yield in the assessment of production balance in enset production region of the country. The experiment was carried out at Areka Agricultural Research Center’s on-station site on a total number of 328 enset plants from the six major enset growing areas of Southern Ethiopia (59, 46, 49, 44, 49, and 81 from Gamo-Gofa, Guragie, Wolaita, Sidamo, Dawro/Waka and Kembata/Hadiya respectively). Plant height and pseudostem circumference were found out to be the best non-destructive enset kocho yield predictors. The R-square value for estimating fermented squeezed kocho yield was about 0.78 with the equation FUNK (kg/plant) = -25.76 + 5.35PH (m) + 20.01PSC (m) describing the relationship of fermented un-squeezed kocho as a function of enset plant height and pseudostem circumference measurements. This research finding recommends the prediction of fermented squeezed kocho yield from the linear relationship with the fermented un-squeezed kocho yield with the equation FSQK (kg/plant) = 0.69FUNK (kg/plant) (with \( R^2 = 0.86 \)). From the slope of linear relation line which was forced through the origin the amount of kocho in un-squeezed kocho is about 69% and the rest 31% will be the moisture. Similarly a linear model was developed to estimate the kocho dry matter content from the un-squeezed kocho yield using the equation Dry matter (kg/plant) = 0.044FUNK (kg/plant). From the linear relationship (with \( R^2 = 0.77 \)) the dry matter content was found out to be only 4.4 kg in 100 kg fermented un-squeezed kocho.
Development of Enset Varieties

Last but not least from the past enset breeding research achievements was the development of enset varieties for best quality and yield of kocho which was conducted on a total of about 400 enset accessions collected from the major enset growing zones (Kembata, Dawro, Gamo-Gofa, Wolaita, Sidama and Gurage) of SNNP Region of Ethiopia. The accessions were evaluated, characterized and maintained at Areka Agricultural Research Center. In the year 2006 about 9 promising enset accessions were selected and laid for further verification for their adaptation, yield (“kocho”) quantity and quality, disease and pest tolerance, at different agro-ecologies of five research centers’ on-station fields and six farmers’ fields. Along with the leading center of Areka the key collaborators were the Holleta, Jimma, Kulumsa Research Centers and the Awada Sub-center and six farmers’ fields at Wonago, Chichu and Areka. The experiment resulted in the identification and release of six enset varieties with merits of best “kocho” yield and quality and registered by the Ministry of Agriculture and Rural Development, Animal and Plant Health Regulatory Department in 2009 and 2010 for early and late set varieties respectively. The varieties are Yanbule, Gewnda and Endale from early maturing (3 to 4 years) and Kelisa, Zerita and Mesena from late maturing (4 to 5 years). Some of the quantitative and qualitative morphological and other traits of the varieties against local checks of early set (Local Check 1) and late set (Local Check 2) are described below in Table 1 and 2. (Yeshitila et al., 2011).

However, in the future variety development of enset should also encompass crossing breeding techniques, to derive enset varieties from crosses between established clones of parents complementary in the trait they possess each of which could contribute a different set of desired genes (e.g. wild with clones having good culinary quality) and to convey selection of varieties having various characteristics by observation during the growing of the genotypes in the field including tests to determine resistance, culinary quality, earliness etc. Further breeding techniques on mutation and genetic engineering should also be carried out especially to develop elite clones resistant to the overwhelming problems of bacterial wilt disease.
Table 1. Average quantitative values of the six released varieties over early and late set local checks

<table>
<thead>
<tr>
<th>AVERAGE QUANTITATIVE VALUES AT MATURITY</th>
<th>Early set varieties (year of release 2009)</th>
<th>Late set varieties (year of release 2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yanbule</td>
<td>Gewada</td>
</tr>
<tr>
<td>Pseudostem height (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research (on-station)</td>
<td>2.35</td>
<td>1.72</td>
</tr>
<tr>
<td>Farmers field</td>
<td>1.86</td>
<td>1.82</td>
</tr>
<tr>
<td>Pseudostem circumference (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research (on-station)</td>
<td>1.44</td>
<td>1.22</td>
</tr>
<tr>
<td>Farmers field</td>
<td>1.01</td>
<td>0.94</td>
</tr>
<tr>
<td>Leaf height (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research (on-station)</td>
<td>4.90</td>
<td>4.10</td>
</tr>
<tr>
<td>Farmers field</td>
<td>3.93</td>
<td>4.05</td>
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<tr>
<td>Leaf width (m)</td>
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</tr>
<tr>
<td>Research (on-station)</td>
<td>1.10</td>
<td>0.90</td>
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<tr>
<td>Farmers field</td>
<td>0.75</td>
<td>0.78</td>
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<td>Leaf number</td>
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<tr>
<td>Research (on-station)</td>
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<td>11</td>
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<td>Farmers field</td>
<td>10.00</td>
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<tr>
<td>Unsqueezed Kocho (t/h/y)</td>
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</tr>
<tr>
<td>Research (on-station)</td>
<td>31.49</td>
<td>22.75</td>
</tr>
<tr>
<td>Farmers field</td>
<td>18.96</td>
<td>17.17</td>
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<tr>
<td>Squeezed Kocho (t/h/y)</td>
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<td></td>
</tr>
<tr>
<td>Farmers field</td>
<td>12.54</td>
<td>11.31</td>
</tr>
<tr>
<td>STARCH VALUES IN BULLA</td>
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</tr>
<tr>
<td>Starch (%)</td>
<td>90.00</td>
<td>92.5</td>
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<tr>
<td>pH</td>
<td>5.49</td>
<td>5.16</td>
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<tr>
<td>Moisture (%)</td>
<td>12.50</td>
<td>13.4</td>
</tr>
<tr>
<td>Viscosity (mm2/sec)</td>
<td>15.70</td>
<td>10.69</td>
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<tr>
<td>Gelatinization (Temp oC)</td>
<td>75.00</td>
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VALUES IN KOCHO AFTER FERMENTATION

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<tr>
<th></th>
<th>62.8</th>
<th>62.07</th>
<th>69.58</th>
<th>66.48</th>
<th>62.17</th>
<th>65.83</th>
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<tbody>
<tr>
<td>Moisture (%)</td>
<td>62.8</td>
<td>62.07</td>
<td>69.58</td>
<td>66.48</td>
<td>62.17</td>
<td>65.83</td>
</tr>
<tr>
<td>Fat/Ether extract (%)</td>
<td>0.11</td>
<td>0.09</td>
<td>0.34</td>
<td>0.1</td>
<td>0.09</td>
<td>0.15</td>
</tr>
<tr>
<td>Protein (N% x 6.25)</td>
<td>0.75</td>
<td>0.76</td>
<td>2.66</td>
<td>1.07</td>
<td>0.64</td>
<td>0.82</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>1.15</td>
<td>1.33</td>
<td>1.23</td>
<td>1.17</td>
<td>1.13</td>
<td>1.24</td>
</tr>
<tr>
<td>Crude fiber (%)</td>
<td>1.59</td>
<td>1.37</td>
<td>1.34</td>
<td>1.76</td>
<td>1.52</td>
<td>1.3</td>
</tr>
<tr>
<td>Zinc (mg/100gm)</td>
<td>2.65</td>
<td>1.7</td>
<td>5.34</td>
<td>8.05</td>
<td>0.76</td>
<td>4.05</td>
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<tr>
<td>Calcium (mg/100 gm)</td>
<td>207.14</td>
<td>264.49</td>
<td>232.9</td>
<td>229.7</td>
<td>190.02</td>
<td>223.4</td>
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<tr>
<td>Iron (mg/100 gm)</td>
<td>6.45</td>
<td>5.25</td>
<td>12.53</td>
<td>10.52</td>
<td>7.85</td>
<td>9.1</td>
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<tr>
<td>Phosphorus (mg/100 gm)</td>
<td>2.48</td>
<td>2.37</td>
<td>2.5</td>
<td>3.03</td>
<td>2.26</td>
<td>2.27</td>
</tr>
<tr>
<td>Total Carbohydrate (%)</td>
<td>34.35</td>
<td>35.14</td>
<td>27.51</td>
<td>30.49</td>
<td>35.09</td>
<td>31.48</td>
</tr>
</tbody>
</table>
### Table 2. Qualitative measurement values of the six released enset varieties

<table>
<thead>
<tr>
<th>Qualitative Data</th>
<th>Early set varieties (year of release 2009)</th>
<th>Late set varieties (year of release 2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yanbule</td>
<td>Gewada</td>
</tr>
<tr>
<td>Growth/leaf habit</td>
<td>Erect</td>
<td>Erect</td>
</tr>
<tr>
<td>Mature leaf shape</td>
<td>Lanceolate</td>
<td>Lanceolate</td>
</tr>
<tr>
<td>Pseudostem Color</td>
<td>Medium Green with Black Patches</td>
<td>Medium Green</td>
</tr>
<tr>
<td>Midrib Upperside Color</td>
<td>Light Green</td>
<td>Light Green</td>
</tr>
<tr>
<td>Midrib Underside Color</td>
<td>Pink Purple with Light Green</td>
<td>Half Yellow Green and half Pink Purple with Light Green</td>
</tr>
<tr>
<td>Petiole Upperside Color</td>
<td>Light Green</td>
<td>Light Green</td>
</tr>
<tr>
<td>Petiole Underside Color</td>
<td>Light Green with Black Patches</td>
<td>Yellow Green</td>
</tr>
<tr>
<td>Leaf Color</td>
<td>Medium Green</td>
<td>Green</td>
</tr>
<tr>
<td>Leaf Tip and Edge Color</td>
<td>Medium Green</td>
<td>Green</td>
</tr>
</tbody>
</table>
Research gaps and Recommendations

Research gaps

- The number of already collected and conserved accessions is far below the expected number of vernaculars in the different growing regions of the country.
- There are also other species of enset distributed in the parts of the world mainly in Africa and Asia which could have different merits for future breeding purpose. However
- Currently, the already collected enset accessions are only conserved in situ in farmers' fields and ex situ at on station field of Areka Agricultural Research Center, without in vitro back up conservation techniques.
- Despite, the attempts made so far on the morphological characterization of the clones, this technique is rudimentary and a well-established taxonomic classification and descriptor list are still lacking.
- Molecular characterization works are also not conducted on the large number of enset accessions collected and conserved at Areka on-station field to strengthen the information obtained from the morphological characterization.
- Enset yield estimation models accounting the inter clonal, age group, agro-ecological, and harvesting time differences to predict the different yield products (kocho, bulla, amicho, and fiber) of an enset plant non-destructively are still lacking. The already developed enset yield estimation model is having a limited use in that the sample clones were considered at one location and only works for ‘kocho’ yield estimation; models for ‘bulla’, ‘amicho’ and fiber yield estimations are not yet developed.
- On the development of enset varieties, very limited attempts have been made so far which is only concentrating on the selection of elite clones from the available accessions through phenotypic evaluation and characterization techniques. Still now no other breeding techniques like crossing, mutation, genetic engineering have been tried to develop new enset varieties, despite the enormous significance of enset in the country.

Recommendations

- Collection should be conducted on both cultivated and wild types of enset clones in the different parts of the country, which have not yet been carried out to the extent of the need. Other species of the genus ensete found in the other parts of the world should also be introduced and preserved.
- Accessions which were collected so far maintained in field gene bank are exposed to all biotic and abiotic aggressions. Therefore in vitro conservation facility should be strengthened to complement the in situ and ex situ conservation.
- Morphological characterization which is conducted so far should be further strengthened and supplemented by molecular characterization techniques by encompassing a large number of accessions.
- Enset yield estimation models accounting the inter clonal, age group, agro-ecological, and harvesting time differences should be developed to predict the different yield products (kocho, bulla, amicho, and fiber) of an enset plant non-destructively.
- Conventional breeding in combination with mutation and molecular breeding is required to further broaden enset genetic base which could contribute towards successful variety development. In general, knowledge of and facilities for
biotechnology research are of paramount importance in the short term.

- As compared to the importance of enset as a food security crop for a large proportion of people in the country, the attention given to strengthen the human power status and facilities of research is very low which need to be re-vitalized by the national development seekers.

**References**


Ethiopian Science and Technology Commission (ESTC): http://www.capitalethiopia.com


Research Experiences on Enset
Biotechnology in Ethiopia: A Review

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²Southern Agricultural Research Institute, Crop Research Process, Hawassa, Ethiopia

Summary

Enset is herbaceous perennial multipurpose crop which is one of the most important food crops for approximately quarter of the population of the country. Though Enset is one of the national commodity crops and grown by large number of population, its production is highly constrained by a number of biotic and abiotic factors. Diseases insects, lack of infection free and high yielding quality planting materials are among the major problems limiting its productivity. Biotechnological tools are one of the interferences in addressing these challenges in support of conventional technologies. During the last few years, some promising methods especially on tissue culture optimization have been developed by different researchers. However, most of those protocols were not reproducible and inefficient that needs further optimization and refining. Recently, a protocol that has enabled to multiply disease free planting material on massive scale has been optimized at Holetta Agricultural Research Center. The application of molecular tools also play an important role especially in identifying and developing marker linked to bacterial wilt resistance or tolerance genes. Similarly, effective management of bacterial diseases requires precise diagnosis and accurate identification of the causal agents through modern techniques like molecular diagnosis. Despite of these potentials, lack of bacterial resistant clone and limited effort to diagnose bacterial pathogen in tissue culture derived plantlets are still some of the gaps that need further investigation. Using the currently optimized protocol, it is possible to produce and supply large number of quality planting material within a short period of time.
Introduction

Enset is a herbaceous perennial crop belonging to the family musaceae (Cheesman, 1947). Both Enset and banana plants are similar in morphology but Enset is larger and thicker than banana plant. The plant composed of leaves, pseudostem, underground corm and adventitious roots. It reaches up to 13 m long and a diameter of 1 m (Birmeta et al., 2002). Unlike banana, the edible part of Enset is prepared from the pseudostem and the underground corm rather than fruits. Enset is diploid (2n=18) species (Cheesman, 1947) including the wild relatives.

Although Enset is adapted to wider climate condition, it usually grows best between altitudinal ranges of 1500 and 3100 meters above sea level (Tsegaye, 2002; Birmata et al., 2004b). Most Enset growing regions have an annual precipitation of 1100 to 1500 mm and a mean temperature of 10-21°C.

Enset is a stable food and multipurpose crop for approximately quarter of the Ethiopian population. It is one of the national commodity crop cultivated by smallholder subsistence farmers mainly in Southern and the central Oromiya regions (CSA, 1997). It plays enormous roles in the socioeconomic of the country. Enset is not only an important food crop but also serves as fibre and important source of feed particularly during the dry season (Bezeneh and Feleke, 1966; Nurfeta et al., 2009). The main edible parts of Enset are the corm and pseudostem. Kocho, Bulla, and Amicho are the major food types obtained from Enset. The fermented product of Enset, Kocho, is rich in carbohydrate and mineral substances like calcium and Iron. It is the bulk of the fermented starch obtained from the mixture of decorticated (scraped) leaf sheathes and grated corm. Bulla which is considered as the best quality of Enset food, which is obtained through a special processes mainly from fully matured Enset plants. 'Amicho' is the boiled Enset corm which contains higher dry matter than any other part of the crop (Nurfeta et al., 2008).

It’s tolerance to abiotic factors and adaptability to wider climatic conditions have enabled Enset for its rapid expansion to different parts of the country. Despite its tolerance to some climatic and environmental fluctuation, the production and productivity of Enset is threatened by different biotic and some abiotic factors. Diseases, insect pests, and lack of high quality planting materials which are free of diseases are the major constraints of Enset production system.
Enset bacterial wilt is one of the major bottle-neck threatening Enset production and productivity. This disease is caused by *Xanthomonas campestris pv musacearum*. The disease causes a yield loss of up to 100% in major growing areas (Ashagrai, 1985). *Xanthomonas campestris* is believed to be originated from Ethiopia (Ndunga et al., 2006). Plants may be affected at any growth stage, including full maturity. The disease can be spread via infected plant material, contaminated farming and processing tools, insects, wind and humans/animals. The incidence and spread of the disease throughout the Enset growing areas of the country is persistently increasing and up to 100% infection have been reported in different areas (Mesfin et al., 2007). These days bacterial wilt is becoming a regional threat as significant yield losses have been reported across East African countries.

Existing research outputs and reports indicated that there are some Enset clones suspected to be tolerant/resistant to bacterial wilt. However, artificial inoculation of previously reported tolerant/resistance Enset clones with bacterial wilt indicated that all clones showed wilt symptoms with different levels of incidence (Welde Michael et al., 2008). Furthermore, they indicated that some of the clones recover after the initial symptom development. Still more investigation is needed to generate reliable information using modern techniques like molecular characterization and development of markers linked to bacterial wilt resistant gene.

### Biotechnological Approaches and Research

#### Achievements in Enset Improvement

Agricultural biotechnology might be considered as an important approach in addressing challenges of various biotic (pests and diseases) and abiotic (inorganic factors such as drought, salinity, and soil fertility) in agriculture. Coupled with conventional technologies, it effectively addresses the problems of food security and increased farmer incomes challenges. Biotechnological tools range from tissue culture to molecular approaches and genetic transformation. *In vitro* techniques and molecular tools are thus one of the potent means of interference especially in producing disease-free planting material and to identify bacterial wilt resistant/tolerant Enset clones. In addition, *In vitro* techniques help in conservation of quality planting material while molecular tools play an important role to identify and develop markers linked to bacterial wilt resistance/tolerance genes, and thereby to use them for marker-assisted selection and breeding for better disease control and to enhance productivity of the crop. Molecular characterization of different Enset
clones helps to identify the existence of tolerance/resistance genes to bacterial wilt. This helps to develop molecular markers and primers linked to the responsible genes. This paper deals with detail review of some of the practical application of in vitro culture and molecular markers for the improvement Enset production and productivity. Some of these activities are summarized in Table 1.

Table 1. Application of biotechnological tools in Enset improvement

<table>
<thead>
<tr>
<th>Biotech approach</th>
<th>Techniques</th>
<th>Purpose</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tissue culture</td>
<td>Shoot tip</td>
<td>Disease free multiplication</td>
<td>Mathew and Philip, 1996; Negash et al., 2000; Birmata et al., 2004b; Diro and Stedan, 2005; HARC unpubl.</td>
</tr>
<tr>
<td></td>
<td>Somatic embryo</td>
<td>Micro propagation</td>
<td>Negash et al., 2000; Mathew and Philip, 2003</td>
</tr>
<tr>
<td></td>
<td>Zygotic embryo</td>
<td>Regeneration</td>
<td>Diro and Stedan, 2004</td>
</tr>
<tr>
<td></td>
<td>Adventitious buds</td>
<td>Micro propagation</td>
<td>Afza et al., 1996; Negash et al., 2000</td>
</tr>
<tr>
<td>Molecular markers</td>
<td>RAPD</td>
<td>Genetic diversity</td>
<td>Birmeta et al., 2002; Birmeta et al., 2004a</td>
</tr>
<tr>
<td></td>
<td>rDNA</td>
<td>Pathogen detection</td>
<td>Birmeta et al., 2004c</td>
</tr>
<tr>
<td>Molecular Diagnosis</td>
<td>AFLP</td>
<td>Genetic conservation</td>
<td>Negash et al., 2002</td>
</tr>
<tr>
<td></td>
<td>RAPD</td>
<td>Pathogen diversity study</td>
<td>Odipio et al., 2009</td>
</tr>
<tr>
<td></td>
<td>Rep-PCR</td>
<td>Pathogen characterization</td>
<td>Arltua et al., 2007; Arltua et al., 2008</td>
</tr>
</tbody>
</table>

**Enset tissue culture**

Plant tissue culture is an important step in plant biotechnology since it facilitates rapid vegetative multiplication (micro-propagation) of valuable plant material for agriculture, horticulture and forestry. Multiplication of single explants into several thousands of plants in very short time allows producing required amount of new quality planting material in time. In addition, through tissue culture techniques, it is possible to produce disease free plants, disease and pest resistant plants and others. Furthermore, plants grown from tissue culture that pass through callus phase are subjected to soma-clonal variations which might also be of breeders’ interest like tolerance to pests, diseases, etc. Through tissue culture, it is also possible safely clone rare and endangered plants and conserve them in ‘tissue banks’ through cryo preservation. This approach can also be applied to conserve explants from superior plants plant cultured in media are easier to export than soil-grown plants, as they are
pathogen free and take up little space (nowadays many companies use this system). The techniques in tissue culture, especially haplodization, also help in increasing selection efficiency for crop improvement. The ability to produce progeny all year-round is also another advantage of tissue culture.

Various *in vitro* culture and *in vitro* conservation researches have been conducted on Enset (Table 1). The success of Enset *in vitro* culture is limited by several factors. Some of the major constraints include; the excess exudation of phonolic compounds during culturing, apical dominance nature of the crop and the presence of endogenous bacteria contamination. Attempts have been made to suppress apical dominance through the application of meristem wounding (Birmata *et al.*, 2004b; Diro and Stedan, 2005). Initiation of several buds from a single explant was achieved through meristem wounding on modified MS medium (Birmata *et al.*, 2004b). However, this protocol has its own drawback of reproducibility. The degree of browning due to phonolic exudation varies form explant to explant (Diro and Stedan, 2005). According to the authors, explants that are collected from *in vitro* grown seedlings showed no blacking while the majority of explants from field grown suckers were lost as a result of extensive blackening when cultured. The use of activated charcoal, supplementing the media with different additives and growing cultures under dark condition can prevent or remove inhibitory phonolic compounds from the media. Establishing and maintaining the mother plant in controlled green house prior to *in vitro* culture reduces the loss of explants as a result of endogenous bacterial contamination (Birmeta *et al.*, 2004c). The current research result showed that the degree of endogenous contamination depends on the size and age of the explant in addition to mother plant management (unpublished data). The smaller and the younger the explant is the little endogenous contamination to occur.

Recently, an efficient disease free *in vitro* multiplication protocol was optimized at Holetta Agricultural Research Center of the Ethiopian Institute of Agricultural Research. This has enabled to produce large number of disease free seedlings within short period of time (Figure 1). The activity involves several stages that ranging from selection and establishment of mother plants to acclimatization of the plantlets in green house and field condition.

*In vitro* conservation of Enset plays an important role in efficient preservation of germplasm. A protocol for *in vitro* conservation of Enset has been achieved through the application of growth retardants in growth medium and keeping the cultures at low temperature (Negash *et al.*, 2001).
Applications of Molecular Markers in Enset

With the discovery of DNA marker technology, several types of DNA markers and molecular breeding strategies are now available to plant breeders and geneticists. Some of these DNA markers include; Random Amplified Polymorphic DNA (RAPD), Restriction Fragment Length Polymorphisms (RFLP), Amplified Fragment Length Polymorphic DNA (AFLP), Single Nucleotide Polymorphism (SNP), Inter-specific Simple Sequence Repeat (ISSR) and Micro satellites (nSSR & cSSR). These are useful tools in various applications like DNA fingerprinting, germplasm conservation and genetic improvements. Limited attempts have been done so far to analyze the genetic diversity of Enset clones as well as their wild relatives using molecular tools such as RAPDs (Birmeta et al., 2002; Birmeta et al., 2004a) and AFLPs (Negash et al., 2002).

Diagnostics and Characterization of Enset Bacterial Wilt

Plant diseases caused by various pathogens have been recognized as one of the most important factors limiting agricultural production. The effective management of these diseases requires precise diagnosis and accurate identification of the causal agents. Traditional methods such as visual inspection of the disease or its symptom, examination under a microscope, pathogen isolation/culturing, biochemical, serology-based methods including ELISA and conducting pathogenicity tests are sometimes inadequate to reveal the nature of the causal agent. Developments in biotechnological tools like monoclonal antibodies and nucleic acid-based methods particularly polymerase chain reaction (PCR) has added a new dimension in the diagnosis of diseases.

The use of rDNA analysis to identify some bacteria and fungi from in vitro and surface sterilized field samples of Enset plantlets was undertaken (Birmeta et al., 2004c). Result showed that both bacteria and fungus were isolated from both samples. Among the isolated bacteria most of them are found to be gram positive. Effort to characterize Xanthomonas campestris pv. musacearum, the causal agent of a wilt of Enset and banana using molecular techniques was undertaken by researchers at different times (Aritua et al., 2007; Aritua et al., 2008). Results showed that these causal agents are homogenous and very similar to other strains isolated from sugar cane and maize. From this genetic relatedness one can speculate that these populations may be evolved from the same ancestor.
Despite of the various conventional and biotechnological applications in Enset improvement, still there is a gap in resistant variety development against bacterial wilt. Furthermore, there is no appropriate means of bacterial wilt identification for tissue culture derived seedlings in the country although morphologically the seedlings appear to be free of any pathogens.

**Discussions**

The application of biotechnology particularly tissue culture plays an important role in Enset improvement. The technology helps to multiply bacterial wilt tolerant and high yielding clones on massive scale in short period of time. The use of meristem or shoot tip culture has enabled one to produce disease free plantlets. The regeneration of whole plant from zygotic embryos strongly assists breeding program of Enset since germination of seeds is quite poor (Negash *et al.*, 2000; Diro and Stedan, 2004a). Multiple shoot induction can be achieved with different media combination but the major factor in multiple shoot induction is meristem wounding technique in order to avoid apical dominance (Birmata *et al.*, 2004b; Diro and Stedan, 2004a). According to Diro and Stedan (2004), increasing the concentration of cytokinin doesn’t have significant difference on multiple shoot induction. The current achievement of large number of multiple shoots from an explant through mersitem wounding (unpublished data) is persistent with the report of Birmata *et al.* (2004b) and Diro and Stedan. (2004a). this further strengthens the role of meristem wounding over plant growth regulator treatments in Enset micro propagation. Meristem wounding should be done with great care otherwise extensive wounding result in callus induction. The currently optimized technology can be applicable for large scale commercial propagation of quality planting material of Enset clones.

Conservation and effective utilization of plant genetic resource contributes to food and nutritional security, poverty alleviation and environmental protection, which are major challenges faced by humankind in the century. Conservation of Enset germplasm can be possible by ex situ conservation of clones. However, traditional method of ex situ conservation of germplasm of vegetatively propagated species like Enset through field maintenance requires very large area of land. In vitro approaches, including tissue culture maintenance and cryopreservation, are recognized as useful tools for medium- to long-term conservation of these clones. Molecular techniques such as AFLP (Negash *et al.*, 2002) and RAPD (Birmata *et al.*, 2002; Birmeta *et al.*, 2004a) analysis are being used for aiding these methods. This plays an important role to study the genetic variations within and among populations. These variations
might be due to several factors such as mutation, introgression, recombination, adaptation to environments and continuous selection. Result from RAPD analysis of Enset clones showed that there is high genetic diversity in wild Enset populations which could be a potential source of useful gene for the improvement of cultivated Enset (Birmeta et al., 2004a).

The lack of appropriate bacterial wilt identification method in tissue culture derived seedlings hinders the effort of further multiplication of the clones on a massive scale.

**Conclusions and Future Prospects**

The various research outputs indicated that application of biotechnology for Enset improvement is feasible for rapid multiplication of disease free planting material, *in vitro* conservation, molecular characterization and development of markers linked to bacteria wilt resistance genes. Shifting of medium status from semi solid to liquid medium during shoot multiplication and rooting would be a strategic step for automation and cost efficiency in disease free multiplication using bioreactors. The current achievement of protocol optimization promises a large scale disease free propagation of Enset in the future. Once this protocol is verified to be successful, it can further be adopted by regional and private tissue culture labs in order to multiply and supply large number of quality planting material using the optimized protocol. The existing *in vitro* multiplied plantlets are morphologically appeared to be free of any pathogen; however, further evaluation of plantlets using appropriate disease diagnostic techniques is mandatory. Methods for pathogen identification should be developed prior to *in vitro* multiplication of the selected clones. Further development or application of molecular tools including co-dominant markers is necessary for the improvement of Enset as well as development of resistant variety against bacterial wilt.

**Acknowledgement**

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References


Research and Development
Experiences on Enset Agronomy

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Abstract

This paper reviews enset agronomy that includes management of enset in the nursery and field. Enset propagation is usually carried out vegetatively using suckers from underground stem, corm; while seed propagation is rarely used. In conventional vegetative propagation, corms from two to three-year-old plants are used at a vegetative phase though farmers use two to six-year-old plants. Apical buds should be removed from mother corms to induce growth of adventitious buds. Planting spaces of the mother corms in the nursery is 1.5x1.5m between plants and rows. Applying farm yard manure of 3kg per planting hole (half at planting and the rest after emergence of suckers) is recommended. On an average, 50-60 suckers emerge from a parent corm in two to three months after corm planting. From a study conducted on enset propagation, halved corms gave earlier differentiation of buds and produced more vigorous suckers than whole and quartered corms. Suckers remain with parent corms at least for one year and then they are transplanted from one to four times until they are transplanted to the main field. In here, spacing of 3m between rows and 1.5m between plants are used under research. A spacing area of 4 to 4.5m² per plant and 10-20t ha⁻¹ farm yard manure can be used in the main field. Results from repetitive transplanting studies showed that enset plants which were transplanted once, twice and thrice flowered at about 104, 234 and 260 weeks, respectively. Those plants that were transplanted once gave more kocho dry matter per hectare and per year than those transplanted twice or thrice. The kocho yield of enset per unit space and time, in terms of edible dry weight and energy, was found to be much higher and followed by the root and tuber crops, than the yields of any other crop cultivated in Ethiopia. Farmers are almost fully dependent on organic fertilizers for enset cultivation. Improving organic matter content of enset farm should be considered in terms of supplying nutrients and also in improving the moisture holding capacity of the soil. Analysis of yield gap between enset grown under optimal and those grown under suboptimal conditions and the relationship of livestock and enset cultivation need to be assessed to address limiting factors in their priorities.

Introduction

This paper deals with enset agronomy experiences in research and development. Agronomy is a branch of agriculture dealing with physical and biological factors including soil management, tillage, crop rotation, breeding, weed control, and climate-related to crop production. It commonly refers to field crops while horticulture (garden culture) is concerned with fruits, vegetables, flowers and
ornamental plants. However, it is customary to consider agronomy as an aspect of horticultural crop management.

A production ecological approach disentangles growth- and yield-defining factors (genetic potential and solar radiation), growth- and yield-limiting factors (water and nutrients) and growth- and yield-reducing factors (weeds, pests and diseases) in agricultural production systems (IAC, 2004). It was further explained that growth- and yield-limiting and growth- and yield-reducing factors can be influenced by agronomic practices under field conditions where measures include fertilization, irrigation and crop protection. Genetic improvement can affect crop performance under all production conditions. In Africa, where few farmers have access to either irrigation or affordable chemical inputs, and where growth- and yield-reducing factors contribute to large pre- and post-harvest losses, farmers’ actual yields are typically a fraction of the genetic potential, even for the current varieties (De Jager et al., 2001 cited in IAC, 2004). In this situation, research may be more efficiently directed at closing the gap by focusing on growth- and yield-limiting and growth- and yield-reducing factors.

Similarly, to improve enset productivity focusing on growth- and yield-limiting and growth-and yield-reducing factors would be important. In this paper, enset agronomic practices, as growth- and yield-reducing factors, with regard to planting material multiplication, nursery management, transplanting, field establishment and management is presented and discussed.

Cultivated enset produces seeds but only after a long juvenile period and even if seeds are produced their germination potential is very low because of seed dormancy. However, wild species of Ensete and in a few cases cultivated ones are also propagated from seed. Therefore, the plant is usually multiplied vegetatively using whole or split corms. In the vegetative propagation, the whole or split corms are used after cutting with some portion of pseudostem and removing apical buds but after uprooting or without uprooting the mother plant (Kefale and Sandford, 1991; Mulugeta and Endale, 1994). Different propagation methods and corm types were compared for vigor and number of suckers (Terefe et al., 1994; Mulugeta et al., 2002). Influence of age of parent plants, size and depth of planting hole for parent corm, amount of farmyard manure used for sucker production were investigated at Areka Agricultural Research Center (Mulugeta et al., 2001; Mulugeta et al., 2008) and the achievements are presented.

Corm for sucker production is mostly planted at a homestead on fertile soil and manure is applied. Suckers emerge in 2-3 months and remain with the parent corm, undisturbed, for about a year and then, transplanted to a nursery or main field. Farmers in Sidama and Gedeo zones, and surrounding areas transplant enset suckers to the main field once, one year after propagation, and thin to regulate population density. In areas like Kambata, Hadiya and Guragie zones young enset plants are
transplanted commonly 2-3 times within nurseries and then to the main field. In
these areas, where repetitive transplanting in nursery is practiced, the suckers are
transplanted from nursery to nursery usually every year or every two years in some
cases and areas. Spacing varies with stages and ages of the transplants, increasing at
each successive transplanting stage. Achievements related to influence of repetitive
transplanting and leaf pruning on dry matter and food production of *enset* and
comparison with yields of other carbohydrate-rich food crops (Admasu and Struik,
2000; Admasu and Struik, 2001) are reviewed and presented.

Corm planting for sucker production in most of the growing areas is carried out
shortly before the rain starts or after the onset of rain, which is mainly from
December to March. *Enset* field is almost exclusively fertilized with farm yard
manure and use of commercial fertilizers is not common. Soil fertility gradients of
*enset* farms were investigated and found to be low in the outfields (Asnakech, 1997;
was also found to be drastically decreased compared to *enset* plants grown in
homestead (Tilahun and Mulugeta, 2005). This paper presents major achievements
on *enset*'s horticultural practices, field management and identifies gaps for future
research interventions.

**Achievements**

Agronomic research activities were started in the 1970s by different researchers of
different institutions. Some of the achievements were published in the Proceedings
of the International Workshop on *Enset* (Tsedeke et al., 1996). This paper presents
research outputs, which were generated and/or reported on agronomic practices
after the first workshop on *enset*.

**Propagation**

Cultivated *enset* produces seeds after a long juvenile period and 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 (Fig. 1).
Embryo development is also sometimes poor. Moreover, *enset* utilizes its stored
carbohydrate during fruiting and eventually dies. It is harvested before or shortly
after flowering thus reducing viable seed production. However, wild species of *Enset*
and cultivated ones are propagated from seed in a few cases. Therefore, the plant is
usually multiplied vegetatively using whole or split corms and grown as clones.
Nevertheless, zygotic embryo culture can be used to generate seedlings from
botanical seeds.
Age of parent plants for sucker multiplication

Age of parent plants used for sucker propagation is between two and six years but usually varies from place to place. Under research, influence of age of parent corms on number and vigor of suckers was investigated at Areka Agricultural Research Center (1994 and 1995) using one to five year-old corms of Hal’a clone (Mulugeta et al., 2001). Their results showed that corms of all age group gave rise to suckers (Fig. 2). However, based on combined analysis of variance, one year-old parent corms gave significantly less number of suckers than the other treatments. Corms from age two to five produced closer number of suckers. However, considering long cycle of propagation in enset, two to three-year-old parent corms can be used for sucker production. Three to four year-old plants are more commonly used in different enset growing areas, which is consistent with findings of this report.
Farmers use whole or split corms to produce suckers. Parent corm is uprooted, apical bud removed and planted. In some cases, based on production tradition or climatic conditions, pseudostem is removed (leaving some portion with corm) without uprooting the corm but apical bud is removed. Propagation methods and corm types were compared for sucker production at Areka Agricultural Research Center (Mulugeta et al., 2002). The result in Table 1 shows that halved corms resulted in more number of suckers when parent corms were uprooted, apical bud removed and planted (Method 1), and mother corms not uprooted but apical buds removed at original site of parent corms (Method 2). Halved corms when used with Method 1 or Method 2 resulted also in earlier emergence of suckers that led to more vigorous suckers than whole or quartered corms.

### Table 1: Number of suckers per plot under different propagation practices

<table>
<thead>
<tr>
<th>Propagation Method</th>
<th>Whole</th>
<th>Corn type</th>
<th>Quartered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method 1</td>
<td>79 cde</td>
<td>110 abc</td>
<td>64 def</td>
</tr>
<tr>
<td>Method 2</td>
<td>113 ab</td>
<td>141 a</td>
<td>89 bcd</td>
</tr>
<tr>
<td>Method 3</td>
<td>94 bcd</td>
<td>52 ef</td>
<td>40 f</td>
</tr>
</tbody>
</table>

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

**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 et al., 2002
Planting depth for halved corms
Depth of planting hole for corms varies based on sizes of the parent corms. To compare depths of planting hole for sucker production, an experiment was conducted using corms of three-year-old Hal’a clone, which were longitudinally split into two halves and planted in holes of different depths. The results showed that in the first year planting at 20 cm depth gave more number of suckers per corm than the rest but the difference among the 20, 30 and 35 cm depths was not significant while the 50 and 60 cm deep holes resulted in significantly less number of suckers although the difference between the two was not significant (Table 2). In terms of growth of suckers, deeper holes (50 and 60 cm) resulted in thinner and shorter plants compared to 20, 30 and 40 cm depths. Therefore, 20-30 cm deep hole has been recommended for planting of halved corms.

<table>
<thead>
<tr>
<th>Depth of planting hole (cm)</th>
<th>No. of Suckers per corm</th>
<th>Pseudo-stem height (cm)</th>
<th>No. of suckers per corm</th>
<th>Plant height (cm)</th>
<th>Pseudo-stem height (cm)</th>
<th>Pseudo-stem diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>50 a</td>
<td>4.4 a</td>
<td>60 a</td>
<td>71.61 ab</td>
<td>8.77 a</td>
<td>2.47 ab</td>
</tr>
<tr>
<td>30</td>
<td>36 ab</td>
<td>4.1 ab</td>
<td>36 ab</td>
<td>85.29 a</td>
<td>14.75 a</td>
<td>3.42 a</td>
</tr>
<tr>
<td>40</td>
<td>35 ab</td>
<td>3.2 ab</td>
<td>26 ab</td>
<td>70.96 ab</td>
<td>11.60 a</td>
<td>2.50 ab</td>
</tr>
<tr>
<td>50</td>
<td>13 b</td>
<td>2.7 ab</td>
<td>8 b</td>
<td>33.73 bc</td>
<td>5.06 ab</td>
<td>0.82 bc</td>
</tr>
<tr>
<td>60</td>
<td>7 b</td>
<td>2.1 b</td>
<td>1 b</td>
<td>15.08 c</td>
<td>1.44 b</td>
<td>0.19 c</td>
</tr>
<tr>
<td>CV (%)</td>
<td>89.6</td>
<td>49.3</td>
<td>104.7</td>
<td>63.11</td>
<td>88.2</td>
<td>77.5</td>
</tr>
</tbody>
</table>

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

Transplanting

Single transplanting
Single transplanting and stand regulation in the main field is commonly practiced in Sidama, Gedio Zones and in other bordering areas. In Sidama, about one year after corm planting, suckers locally called Funta, are uprooted with a mother corm, detached and sorted out into two size groups of weak and vigorous suckers. One or two times transplanting are common (Spring, 1996). The vigorous suckers are directly transplanted into the main field and planted at narrow spacing (50 to 75 cm apart) while the weak ones are planted in a nursery in a group of 2-3 suckers per hole for a year of further growth and development. Farmers give different names to a plantation in the main field every year as plants age and size increase (Table 3). Suckers stage (Funta) is transplanted into the main field at an area of about 0.3m² per plant and takes a local name Kora after one year. Kora is thus two-year-old enset plantation, which is one year in the nursery plus one year in the main field. When they are three-year-old, the plants are locally named Ketelo at the same place in the main field. At this stage, weak plants (Dukulo) are thinned to improve spacing and reduce competition among the remaining plants. The remaining plants occupy 0.5-
1m² per plant. *Dukulo* plants are planted in a narrow spacing with younger plants of the same size. After one-year growth, *Ketelo* is named *Simancho*. Thus, *Simancho* is a four-year-old enset plantation. At this stage, plants are also thinned to regulate stands and the thinned plants are mainly used as mother plants to produce suckers while corms can also be cooked and consumed. Pseudostem and leaves are used as feed for cattle. At *Simancho* stage each plant occupies an area of about 1m². After a year, the remaining plants take the name *Mallancho*, which is a five-year-old enset plantation. At this stage too, thinning is carried out to optimize plant population density. Thinned plants are processed into kocho with mature plants or their corms are consumed. When the plantation attains an age of six, it is called *Itancho*. Plants in this stage are mature enough for processing into kocho. Some of the plants may flower and take the name *Kalimo*.

**Repetitive transplanting**

Repetitive transplanting is used in areas such as Kambata, Hadiya, Gurage and South West Shewa. Here, the experiences of Gurageis considered describing multiple transplanting in nursery. The mother corm is planted at a spacing of about 1.5 x 1.5 m. Two to three months after mother corm planting, suckers emerge and stay with the mother corm for about a year. These suckers are called *Fonfo*. Suckers from *Fonfo* stage are sorted out into size group of small and big. The smaller ones are called *Ariye* and replanted in a group for further growth and development. The bigger ones are transplanted into *Simmua*. Thus, *Simmua* are suckers that have been transplanted once and can be planted in rows with two to three suckers in group or in rows of single plants (Spring *et al.*, 1996). The same authors explained that the spacing between grouped plants of *Simmua* stage is about 1m x 1m and within the group 0.2m. Planting of this type of sucker is carried out on the onset of the small rainy season, usually in February and March.

After one year in *Simmua* stage, suckers are uprooted and transplanted into next stage, *Tiket*. Thus, *Tikets* are suckers that have been transplanted twice. Spacing used at this stage is about 1m x 1m, between rows and plants. At the end of one year, either the suckers are transplanted to the next stage or the leaves are defoliated mainly to intercrop maize. The defoliated plants in *Tiket* stage are called *Girdem*. Suckers stay in *Tiket* stage for one or two years and transplanted for the third time to *Hiba* stage. Plants stay in this stage for one or two years and transplanted to main field, where it is left until maturity. Spacing used at this final stage is about 2.5m x 2m, between rows and plants, respectively. Plants in this stage are called *enset* and need about three to four years to be harvested for kocho. The total time required from propagation to harvesting is about seven to eight years in the mid-altitude areas and even more than 12 years in cooler high altitude areas.

Single and repetitive transplanting and leaf pruning study was carried out to define *enset* production systems (Admasu and Struik, 2000). From the results, it was observed that enset plants transplanted once, twice and thrice flowered within 104,
234 and 260 weeks after transplanting, respectively. Leaf pruning did not affect the rate of progress from planting to flowering. At 104 weeks after transplanting, fresh kocho yield was higher for once transplanted corms than those transplanted twice or thrice (Table 4). Leaf pruning significantly reduced kocho yield of once transplanted plants. For transplanting twice and transplanting thrice, leaf pruning did not significantly affect production rates of fermented kocho. At 130 days after first transplanting, transplanting thrice resulted in significantly lower production rates of fermented kocho, both with and without leaf pruning.

The maximum fresh weights of kocho after fermentation from enset plants transplanted once, twice and thrice were 25.9, 54.1 and 37.1 kg/plant, respectively (Admasu and Struik, 2001). When yield was expressed per unit of space and time, the maximum fresh yields of fermented kocho (70% moisture) were 19, 33 and 26 t ha⁻¹.⁻¹, respectively. Transplanting once, therefore, can be used to have early harvesting while twice transplanting is recommended for final higher kocho yield.

Table 3: Local names and stages of enset in nursery and main field in different growing areas

<table>
<thead>
<tr>
<th>No.</th>
<th>Stages of enset</th>
<th>Sidama (Thinning and naming of stages)</th>
<th>Wolaita</th>
<th>Hadiya</th>
<th>Gurage</th>
<th>SW Shewa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Suckers on mother corm</td>
<td>Funta</td>
<td>Hata</td>
<td>Dubbo</td>
<td>Fono</td>
<td>Nedo</td>
</tr>
<tr>
<td>2</td>
<td>Once transplanted/2nd stage</td>
<td>Kora</td>
<td>Beshasha</td>
<td>Sima</td>
<td>Sam’a</td>
<td>Delge</td>
</tr>
<tr>
<td>3</td>
<td>Transplanted twice/3rd stage</td>
<td>Ketelo</td>
<td>Gardua</td>
<td>Ogoja/Ero</td>
<td>Tiket</td>
<td>Mesiey</td>
</tr>
<tr>
<td>4</td>
<td>Transplanted thrice/4th stage</td>
<td>Simancho</td>
<td>-</td>
<td>-</td>
<td>Hibe</td>
<td>Ebyba</td>
</tr>
<tr>
<td>5</td>
<td>Thinning stage for Sidama/5th stage</td>
<td>Mallancho</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Enset plants in the main field before flowering</td>
<td>Itancho</td>
<td>Halla</td>
<td>Belesa</td>
<td>Eset</td>
<td>Teqa</td>
</tr>
<tr>
<td>7</td>
<td>Flowered enset plants</td>
<td>Kalimo</td>
<td>Wosa</td>
<td>Kalima</td>
<td>Borena</td>
<td>Shiya kan base</td>
</tr>
</tbody>
</table>

Table 4: The effect of number of transplanting and leaf pruning on fresh weight (kg/plant) of fermented kocho harvested and processed at different weeks after removal from the mother corm

<table>
<thead>
<tr>
<th>Transplanting (A)</th>
<th>Leaf pruning (B)</th>
<th>Weeks after removal from the mother corm (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>104</td>
</tr>
<tr>
<td></td>
<td>Not pruned</td>
<td>18.6</td>
</tr>
<tr>
<td></td>
<td>Pruned</td>
<td>14.6</td>
</tr>
<tr>
<td>Twice</td>
<td>Not pruned</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>Pruned</td>
<td>4.2</td>
</tr>
<tr>
<td>Thrice</td>
<td>Not pruned</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>Pruned</td>
<td>1.5</td>
</tr>
<tr>
<td>CV%</td>
<td></td>
<td>21.0</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td></td>
<td>2.3*</td>
</tr>
</tbody>
</table>

*P < 0.09, *indicates significant difference between treatment at P < 0.05; NS = non-significant.

Source: Admasu and Struik, 2001

Soil fertility management in enset field

Farmers apply almost exclusively organic waste to enset field year after year. Amount of organic waste applied depends up on its availability, which in turn
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depends up on number of animals owned by the household. Farmyard manure (FYM) of 10-20t ha\textsuperscript{-1} y\textsuperscript{-1} may lead to better growth and yield of enset (Personal observation). Preliminary results show that the use of 250kg Urea and 100kg DAP ha\textsuperscript{-1} y\textsuperscript{-1} for two years resulted in better growth and yield of enset (Abay, 2010, unpublished). Research was conducted on farmers fields of resource rich, group I (G1) and poor (G2) for four years (2001-2004) at Gununo, Southern Ethiopia (Tilahun and Mulugeta, 2005). The objectives of the study were to evaluate the effect of soil fertility gradients on enset growth, identify the major growth limiting nutrients and identify farmers' decision making criteria in allocating organic resources to various crops.

Enset transplants were planted in homestead and outfields and application of fertilizers by farmers to different units over seasons and years was recorded and enset growth and nutrient content were measured. The results showed that G1 farmers produced two times more organic waste than G2. About 80\% of the organic waste produced was allocated for maintaining soil fertility, while 20\% being allocated as a cooking fuel (Table 5). From organic waste allocated for soil fertility maintenance, 65\% was allocated for the enset field in the homestead.

There was significantly higher N, P, K and Ca content in the homestead soils than in the outfields, regardless of farmers' resource endowment. The P (0.5-1 ppm) content of the outfield was the lowest, less than 25\% of the P (2.5-10 ppm) content of the homestead. Similarly, organic matter in the outfield (2-2.8\%) was lower than that of the homestead (5-6\%). Enset plants grown in the outfields experienced about 90\% reduction in height and 50\% reduction in pseudostem diameter, regardless of resource categories. The NPK content of the plant tissues grown in the outfields was significantly higher, in some cases up to 150\%, than those planted in homestead. It can thus be stated that growth reduction of enset in the outfield was not directly related to NPK deficiency, but it could have been caused by off-season moisture stress in the outfields, manifested by low soil organic matter.

Farmers were asked for five major reasons for applying most of the organic waste in the homestead year after year, The following were their response: 1) there is no enough organic matter to apply in sufficient amount all over the farm (100\%), 2) the most important crops are in the homestead (mostly enset, coffee and taro), 3) enset is traditionally grown in the homestead and the use of organic matter follows it, 4) there is lack of labor to carry the organic matter to the outfields (33\%) and 5) soil erosion will remove the organic matter (33\%) if applied in the outfield (Tilahun and Mulugeta, 2005). Therefore, shortage of farmyard manure and importance of homestead crops are the major criteria to allocate organic waste to different fields.
Table 5: Organic resource production by farmers and its distribution to different farm sub-units in Areka, 2002

<table>
<thead>
<tr>
<th>Farmers' category</th>
<th>No. of animals</th>
<th>Organic manure (kg/week)</th>
<th>Use (%)</th>
<th>Distribution in the field (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cattle</td>
<td>Sheep</td>
<td>FYM (wet)</td>
<td>Others</td>
</tr>
<tr>
<td>G1</td>
<td>4</td>
<td>2</td>
<td>101.5</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>72.5</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1</td>
<td>116.0</td>
<td>11.5</td>
</tr>
<tr>
<td>Mean</td>
<td>3.7</td>
<td>1</td>
<td>96.7</td>
<td>12.9</td>
</tr>
<tr>
<td>SE</td>
<td>0.3</td>
<td>0.6</td>
<td>12.8</td>
<td>1.1</td>
</tr>
<tr>
<td>G2</td>
<td>2</td>
<td>0</td>
<td>72.5</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>2</td>
<td>29.0</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>58.0</td>
<td>6.2</td>
</tr>
<tr>
<td>Mean</td>
<td>1.3</td>
<td>0.7</td>
<td>53.2</td>
<td>7.2</td>
</tr>
<tr>
<td>SE</td>
<td>0.7</td>
<td>0.5</td>
<td>12.8</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Source: Tilahun and Mulugeta, 2005

With regard to inorganic fertilizer, 250kg Urea and 100kg DAP per year for the first two years were recommended for Areka and other similar areas to get higher yield (Abay, 2010, unpublished). However, soil fertility is location specific and fertilizer trials may be needed for different locations along with its profitability.

**Enset productivity compared to other carbohydrate-rich crops**

The kocho yield of enset, in terms of weight and energy, was investigated at Areka Research Center, Southern Ethiopia, and compared with the yields of other main starch crops grown in the country (Admasu and Struik, 2001). The results showed that edible dry matter produced was higher from enset (2425 g per m² per harvest) than that from root and tuber crops (177 g per m² per harvest) and cereals (104 g per m² per harvest). In terms of per day productivity, enset gave 1.72 g m⁻² day⁻¹ edible dry matter followed by 1.01 g m⁻² day⁻¹ from root and tubers while cereals produced 0.69 g m⁻² day⁻¹ (Table 6). Therefore, kocho yield of enset per unit space and time, in terms of edible dry weight and energy, was much higher than the yields of other carbohydrate-rich crops and cereals cultivated in Ethiopia.
### Table 6: Average yields and edible dry matter production rates of major crops grown in Ethiopia as compared with enset under different crop establishment methods

<table>
<thead>
<tr>
<th>Crops</th>
<th>Yield (g m⁻² harvest⁻¹)</th>
<th>Edible portion (%)</th>
<th>Dry matter (%)</th>
<th>Edible dry matter (g m⁻² day⁻¹)</th>
<th>Growth period (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enset (Ensete ventricosum) (Average)</td>
<td>10154</td>
<td>80</td>
<td>30</td>
<td>2425</td>
<td>1339</td>
</tr>
<tr>
<td>Transplanted once</td>
<td>3666</td>
<td>80</td>
<td>32</td>
<td>944</td>
<td>730</td>
</tr>
<tr>
<td>Transplanted twice</td>
<td>14958</td>
<td>80</td>
<td>30</td>
<td>3590</td>
<td>1643</td>
</tr>
<tr>
<td>Transplanted thrice</td>
<td>1817</td>
<td>80</td>
<td>29</td>
<td>2742</td>
<td>1643</td>
</tr>
<tr>
<td>Cereals (Average)</td>
<td>121</td>
<td>100</td>
<td>86</td>
<td>104</td>
<td>140</td>
</tr>
<tr>
<td>Teff (Eragrostis tef)</td>
<td>94</td>
<td>100</td>
<td>89</td>
<td>83</td>
<td>120</td>
</tr>
<tr>
<td>Barley (Hordeum vulgare)</td>
<td>104</td>
<td>100</td>
<td>87</td>
<td>90</td>
<td>150</td>
</tr>
<tr>
<td>Wheat (Triticum durum)</td>
<td>147</td>
<td>100</td>
<td>87</td>
<td>128</td>
<td>150</td>
</tr>
<tr>
<td>Maize (Zea mays)</td>
<td>159</td>
<td>100</td>
<td>80</td>
<td>127</td>
<td>150</td>
</tr>
<tr>
<td>Sorghum (Sorghum bicolor)</td>
<td>126</td>
<td>100</td>
<td>85</td>
<td>107</td>
<td>150</td>
</tr>
<tr>
<td>Finger millet (Eleusine coracana)</td>
<td>97</td>
<td>100</td>
<td>89</td>
<td>86</td>
<td>120</td>
</tr>
<tr>
<td>Root and tuber crops (Average)</td>
<td>781</td>
<td>85</td>
<td>29</td>
<td>177</td>
<td>193</td>
</tr>
<tr>
<td>Irish potato (Solanum tuberosum)</td>
<td>713</td>
<td>85</td>
<td>20</td>
<td>121</td>
<td>120</td>
</tr>
<tr>
<td>Sweet potato (Ipomoea batatas)</td>
<td>821</td>
<td>85</td>
<td>30</td>
<td>209</td>
<td>150</td>
</tr>
<tr>
<td>Cassava (Manihot esculenta)</td>
<td>688</td>
<td>83</td>
<td>40</td>
<td>228</td>
<td>270</td>
</tr>
<tr>
<td>Taro (Colocasia esculenta)</td>
<td>932</td>
<td>85</td>
<td>30</td>
<td>237</td>
<td>210</td>
</tr>
<tr>
<td>Yam (Dioscorea sp.)</td>
<td>750</td>
<td>85</td>
<td>27</td>
<td>172</td>
<td>270</td>
</tr>
</tbody>
</table>

*+g m⁻² based on average spacing*

### Gaps

Yield gap due to better agronomic practices in enset cultivation has not been quantified and the most limiting agronomic practices have not been identified. Some farmers produce very high yield per plant and per unit area of land, which can be exemplified by very high productivity of enset in some farmers’ field of Sheka zone, Southwestern Ethiopia. Understanding extent of the gap and identifying the reasons behind would be helpful to narrow the gap in order to improve the productivity of enset. Animal manure is badly needed for enset production, but availability depends on the number of animals owned by the farmers. Enset on the other hand plays an important role to feed animals/livestock. Animals’ byproducts (meat, milk, egg) are also important to supplement protein, which is low in enset produce. Therefore, the relationship between animal rearing and enset cultivation need further investigation to develop both together, while looking for alternative organic and/or inorganic sources at the same time. The influence of agronomic practices on growth- and yield-reducing factors such as diseases and insect pests and identifying sound cropping system need further study.
Discussion

Propagation
Seed propagation is not common and there is no need to promote it for *enset* cultivation as vegetative propagation produce suckers with better growth and uniformity. However, seed propagation would be important for varietal improvement and conservation of germplasm. Under such condition *in vitro* germination of zygotic embryo can be used to regenerate seedlings from botanical seeds (Mulugeta and Van Staden, 2004). In vegetative propagation, halved corms produced a large number of final suckers when planted immediately after removal of apical buds or when left undisturbed for a year after removing apical buds. However, less number of suckers was obtained from halved and quartered corms when mother corms were transferred to new planting holes three months after removal of apical buds, which could be due to the damage caused to suckers while corm splitting.

Halved corms can be used to propagate *enset* in most of the *enset* growing areas for better number and growth of suckers especially in light of the need to replace *enset* plantation devastated by *enset* bacterial wilt. Nevertheless, farmers often use different propagation methods considering the prevailing environmental conditions. These include: whole corm is, for instance, used in areas where dry planting is exercised, hoping rain will start some time after planting; apical bud removal without uprooting the parent corm is preferred for low-moisture stressed areas because root-to-soil relationship stay undisturbed. Experiments on propagation were carried out at Areka Agricultural Research Center and would not represent different environmental conditions of farmers.

With regard to age of parent corms, two to three year-old plants can be recommended for sucker propagation to shorten cycle of propagation but the use of three to four year-old plants (*Simantu* in Sidama, *Gardua* in Wolaita, *Ogoja/Ero* in Hadiya, *Hiba* in Gurage and *Eyiba* in SW Shewa, for example) at their vegetative phase is currently used in *enset* growing areas and it is consistent with the findings and thus no need to change it. However, when suckers are needed to establish new plantation or re-establish plantation devastated by bacterial wilt, it is possible to multiply suckers from younger (2-3 year-old) parent plants. Depth of hole for halved corm planting has been recommended to be 20-30 cm but size of the hole depends on age-size of the parent corms. In the future, influence of planting depth on growth- and yield-reducing factors such as *enset* root mealy-bug infestation should be taken into consideration.

Transplanting
Under field experiment, prolonged time from first transplanting to flowering increased fresh and dry matter yield of fermented *kocho* per plant or per unit space and time of once and twice transplanted plants. This could be because of prolonged
interception of photosynthetically active radiation by the crop and opportunity for uptake of N and other nutrients especially under low input conditions. Plants transplanted thrice, showed decreased fresh and dry matter of fermented kocho per plant or per unit space and time at flowering due to the occurrence of corm rot which might be aggravated by transplanting shock due to several times transplanting (Admasu and Struik, 2001).

In areas where single transplanting is used, farmers plant suckers first using narrow spacing and subsequently regulate stands increasing spacing between plants from stage to stage. Thinned out suckers are used for different purposes. Single transplanting (transplanting once) was not a similar treatment with farmers practice, as it was transplanted using wider spacing, and thus results are not comparable. In areas where repetitive transplanting is used, farmers practice it with defined objectives. They use nurseries to produce vigorous transplants that withstand competition when planted as substitute of harvested plants in an already established plantation and thrive in relatively poor soil as it is planted away from the homestead. It is therefore difficult to include farmers practice as treatments in evaluating repetitive transplanting. However, when new plantation is to be established or plantation damaged by bacterial wilt is to be re-established, transplanting once can be used to get reasonably good early harvest for kocho yield or transplanting twice can be used to get better final yield, but only if coupled with better crop management practice.

**Soil fertility management in enset field**

The use of organic fertilizer (FYM) in enset cultivation is the major means for soil fertility management. It will also continue to be the major means as enset is mainly used as a food security crop than for a market. Assessment made in different enset growing areas showed about 4-7 kg plant\(^{-1}\) y\(^{-1}\) fresh dung with beddings is used to fertilize enset in the main field but some use more depending on the number of livestock they owned (UNDP, 1996). It can therefore be indicated that 10-20t ha\(^{-1}\) y\(^{-1}\) is being used. Estimation of amount of FYM used in enset field by farmers is difficult because FYM is applied continuously based on availability of organic waste.

From organic waste allocated for soil fertility maintenance, 65\% is allocated for the enset field in the homestead and organic matter in the outfield was only about 40\% of the homestead (Tilahun and Mulugeta, 2005). Asnakech (1997) also reported that fields where enset had been continuously cultivated for several decades had higher organic matter contents and better nutritional status than non-enset fields. Soil fertility is being maintained, and even increased, in farm components such as the enset-garden, darkua (area near to the homestead planted usually with maize) and taro fields (Eyasu, 1998). It was also emphasized that erosion does not occur in these fields, probably because of high organic matter and a more stable soil structure, the presence of mulch material and greater care provided by the farmers.
The preferential application of organic waste to the homestead was partly because of the limited manure available due to reduced number of animals and partly as a result of decline in farm size which resulted in fewer opportunities to produce and apply cattle manure and crop residues (Tilahun and Mulugeta, 2005). It was also emphasized by Eyasu (2000) that households with no or few animals, lack access to manure as it is becoming an increasingly valuable resource.

**Productivity of enset**

Comparison of the edible dry matter and energy production rates of enset with the production rates of main crops grown in Ethiopia is difficult because of the following reasons: 1) The average edible dry matter and energy yields of main crops considered were calculated using yield data reported by Ethiopian Central Statistics Authority and Southern Nations, Nationalities and Peoples’ Regional Government Bureau of Agriculture; 2) The average edible dry matter and energy yields of kocho were taken after a considerable loss of dry matter due to the complicated traditional harvesting and fermentation processes; 3) The growth period within a crop may show variation depending on the cultivar, altitude, cultural practices, etc. For example, there are some sweet potato and maize cultivars that have shorter growth period but there are also other cultivars with a much longer growth period (Admasu and Struik, 2001).

The comparison, however, showed that the edible yield of enset (weight and energy) is much higher than that of cereals or root and tuber crops, which could be due to the longer growth period of enset. Therefore, the cultivation of enset in densely populated areas under low input conditions can sustain the population better than any other crop. Food products from enset are low in proteins and vitamins and needs supplementing with legumes, vegetables and fruits. Enset has also other advantages where its perennial canopy intercepts heavy rain and reduces soil temperature and, thereby, protects the soil against erosion, decreases organic matter decomposition and reduces leaching of plant nutrients and thus contributes to sustainable production system.

There are several factors that make enset yield measurement difficult (Hiebsch et al, 1997). This is because enset: has harvested products with high and variable moisture content; has several harvestable products with different uses; may be intercropped with other crop species; is a multiple-year crop; is transplanted from one to four times at wider spacing; may be harvested at different ages or stages; may be harvested at any time during the year; and often has stands with a mixture of clones that have similar growth rates and uses.
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Research Achievements, Experiences and Future Direction on Bacterial Wilt of Enset

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Abstract

Enset (Ensete ventricosum) is one of the most important staple food crops in Ethiopia. However, its production has been threatened by a devastating bacterial disease caused by Xanthomonas campestris pv. musacearum. This disease was officially reported in Ethiopia for the first time in the 1960’s. It is a vascular disease resulting in yellowing of the leaves, wilting and finally collapsing of the entire plant. The pathogen is known to survive in the soil, plant debris, on surface of contaminated knife, alternative host plants and spread by any object that comes in contact with contaminated plant parts and domestic and wild animals. Currently, cultural practices and effective sanitary control measures are one of the most principal control measures for the disease. This paper presents a review of works done on the disease, research gaps and future research perspectives.

Keywords: Enset, bacterial wilt, research achievements, future research respective

Introduction

Enset (Ensete ventricosum) is one of the most important staple food crops in Ethiopia. The plant is drought tolerant and multi-purpose crop. All plant parts are utilized for different purposes. Hence, kocho, bulla and amicho are used as human food. The by-products from the plant is used to make different household items. Fresh enset leaves are used as bread and food wrappers, cattle feed, serving plates, and pit liners to store kocho for fermentation (Brandt et al., 1997). Though, the plant has multi-purpose uses, it is principally cultivated for its carbohydrate rich food products. It is used as staple or co-staple food for about 20 % of Ethiopian population particularly in the South and South-western part of the country (Brandt et al., 1997). Due to its drought tolerance, enset is regarded as one of the priority crops in Ethiopia, as it makes major contribution to the food security scheme of the country. Regions where enset is used as staple or co-staple food are usually less affected by the recurrent drought periods that occur in Ethiopia (Brandt et al. 1997).
However, notwithstanding the fact that the plant makes immense contribution to the food security of the country, there are lots of biotic and abiotic problems facing *enset* production. Among the biotic constraints, diseases caused by bacteria, nematodes, fungi and viruses; mammalian pests such as porcupine, mole rat, and wild pig and insect pests such as mealy bugs have been identified as serious problems. Of all the biotic constraints, bacterial wilt disease, which is caused by *Xanthomonas campestris* pv. *musacearum* (Xcm), (Yirgou and Bradbury, 1968, 1974) has been the most threatening one. *Enset* bacterial wilt, is known to cause severe damage, as it attacks and kills the plants at any growth stages, including full maturity (ready for harvest). Once the plants are attacked by the disease, especially at late maturity stage, it affects whole systems, and usually causing a maximum yield loss. A serious outbreak of the disease was reported by Ashagari (1985) with losses of up to 70%. The results obtained from recent bacterial wilt disease assessment made in some *enset* fields of the Southern Nations, Nationalities and Peoples Regional State (SNNPR), showed losses of up to 100% under severe damage (Shank and Chernet, 1996, Anonymous, 2008). Many researchers (Anita *et al.*, 1996; Shiferaw, 1998; Tsegaye *et al.*, 1998; Million *et al.*, 2003; and Endale *et al.*, 2003) reported that both the area and productivity of *enset* is declining continuously due to this disease. Therefore, this paper is aimed at reviewing research achievements and experiences gathered through the years on this deadly disease of *enset* and provide an indicative approach to future research directions.

**The Pathogen: *Enset* Bacterial Wilt**

In Ethiopia, a disease symptoms similar to bacterial infection of banana, known as Moko disease or bacterial wilt was reported on *enset* for the first time in the 1930’s (Florence, 1939). However, a bacterium causing a wilt disease of *enset* was officially reported in Ethiopia for the first time in the 1960’s (Yirgou and Bradbury, 1968) and named *Xanthomonas musacearum*. The same bacterium was later confirmed as causing a similar disease on cultivated banana and other *Musa* spp. (Yirgou & Bradbury, 1974) and was subsequently reclassified as *X. campestris* pv. *Musacearum* (Young *et al.*, 1978).

*Enset* bacterial wilt is a vascular disease (Thwaites *et al.*, 2000) that results in yellowing of the leaves, wilting and finally collapsing of the entire leaves/plant (Figs. 1A and B).
Symptoms: The symptoms, which include yellowing of leaves, wilting (often associated with loss of turgor and collapse of the petiole) and excretion of a yellowish bacterial ooze from cut tissues is characteristic of both banana and *Enset* bacterial wilt (Thwaites *et al.*, 2000; Tushemereirwe *et al.*, 2003, 2004). A cream or yellow-colored ooze, typical of many bacterial infections, exudes within a few minutes after cutting the tissue and abundant quantities may be produced over a period of several hours.
Taxonomy and Nomenclature of the Pathogen

Biochemical and cluster analysis studies conducted in Ethiopia on enset and banana Xcm isolates indicated that there are variations among isolates (Quimio, 1992; Gizachew, 2000; Kidist, 2003). Phenotypic characterization and PCR-based studies conducted on both enset and banana Xcm isolates from Ethiopia also revealed possibility of variation among the isolates (Tsehay, 2009). However, studies done on Ugandan isolates of Xcm using Random Amplification of Polymorphic DNA (RAPD) analysis did not reveal any significant differences in clustering, with exception of a single isolate that had unique fingerprints. All the isolates compared also showed no significant difference with regard to incubation period for appearance of symptoms and the severity of symptoms in pathogenicity test (Odipio et al., 2009). Molecular studies conducted by fatty acid methyl esters, genomic fingerprinting using rep-PCR and partial nucleotide sequencing of the gyrase B gene on Xcm, indicated that strains of Xcm have close homology to strains of Xanthomonas vasicola. Therefore, the result of this study suggests for reclassification of X. campestris pv. musacearum as X. vasicola pv. musacearum (Aritua et al., 2007). But this has not been formally approved as a new combination of names (Karamura et al., 2008). However, some reports have already reported Xanthomonas vasicola pv musacearum (Xvm) as causative agent of Bacterial wilt disease of enset and banana in South and South-western part of Ethiopia (Shimelash et al., 2008) and in Eastern Africa (Biruma et al., 2007). Karamura et al. (2008) have also listed enset as a host plant of X. vasicola pv. musacearum.

Sources of Inoculums, Mode of Infection and Transmission of Xcm

Concerning sources of inoculum, mode of infection and transmission of Xcm especially of enset in Ethiopia is not yet well studied to the level needed as compared to the seriousness of the disease. However, a few studies have generally revealed some facts on sources of inoculum, mode of infection, transmission and survival of Xcm.

Studies done to understand survival of Xcm in the soil indicated that the pathogen can survive in the soil for some specified time (Quimio and Mesfin, 1996; Mwebaze et al., 2006; Welde-Michael et al., 2008). The result of a preliminary work showed that the bacteria can survive in chopped plant debris in the soil for over six months. It was also indicated that, plant residues, contaminated soils and water (overflow of water from infested to uninfested fields), infected mats and traded products including fruits, leaves and planting materials (suckers and corms) are thought to be the major sources of inoculum of Xcm (Mikias et al., 2010; Eden-Green, 2004; Million et al., 2003). The findings of other studies also revealed that Xcm survived on the surface of contaminated knife for up to 3 to 4 days (Ashagari, 1985) and found to transmit the pathogen from infected to healthy plants (Welde-Michael et al., 2008). Generally, it was also reported that the pathogen is easily spread by any object that comes in contact with contaminated plant parts (Brandt et al., 1997). Xanthomonas campestris pv musacearum was observed to survive in pruned leaf petioles and leaf sheaths for at least 3 months (Welde-Michael et al., 2008). Plant families of
Cannaceae (Cana family), Costaceae (Costus family), Heliconiaceae (Heliconia family), Marantaceae (Prayer-plant family), Strelitziaceae (Birds of Paradise Flower family) and Zingiberaceae (Ginger family) are considered as host plants (Karamura et al., 2008) and could be possible source of inoculum for the pathogen.

Works done on dissemination mechanism of the pathogen have indicated to be mediated by several factors. Study on insect transmission of Xcm on enset suggested the possibility of transmission of the pathogen by insect vectors (Wondimagegne, 1981). Similarly farmers also claim that the pathogen is transmitted by insect vector (Tariku Hunduma, personal communication). However, this fact is not yet fully clarified. Insect mediated transmission of Xcm on banana identified potential insect vectors and the importance of these vectors in ABB bananas through the male buds has been underlined by the fact that early de-budding readily arrests disease spread (Karamura et al., 2008).

Contaminated tools used in routine field activities (pruning, de-leafing, digging, weeding and harvesting) are key mechanism by which the disease spread locally within the same farm and between farms (Mikias et al., 2010; Karamura, 2006; Million et al., 2003).

Vertebrate pests such as mole rats and porcupine are claimed to transmit the disease (Mikias et al., 2010; Brandt et al., 1997; Shank, 1996). Domestic animals such as cattle are also expected to spread the disease (Mikias et al., 2010). Though evidences from banana has demonstrated the potential of bats and birds to transmit the disease (Karamura et al., 2008), there is no evidence in the case of enset Xcm. These organisms need to be taken into consideration and cannot be undermined as vectors of the disease. Study conducted on banana on the entry of the pathogen suggested to be facilitated by mechanical injuries or injuries caused by soil-borne organisms such as nematodes and insects. However, this needs further investigation in the case of enset.

Management of Enset Bacterial Wilt Disease

Lack of adequate information on the biology and epidemiology of the pathogen and the perennial nature of the plant have affected the development of effective control measures as yet. Consequently, management options have focused on methods that reduce the initial inoculum and subsequent spread of the pathogen.

Cultural practices and sanitary control measures are one of the most principal control measures for enset bacterial wilt disease. Regular inspection of fields and effective eradication of inoculum would contribute immensely to lower the level of infection. Practices such as disinfecting farming and processing tools by washing them in Sodium hypochlorite (Berekina) and with fire (Karamura et al., 2008) have been known to reduce disease transmission from infected plant to healthy one. According to these authors, the solution can be prepared by mixing one cup of berekina in five cups of water. As diseased enset plants and debris are the potential sources of primary inoculum, uprooting and burying the infected enset plants
(eradication and disposal of diseased enset plants/debris from the fields) has also resulted good management options. Karamura et al. (2005) identified early detection and destruction of the diseased plants as a key step in preventing disease spread. Cultural and sanitary measures have been practiced by farmers in different enset growing zones of the country. According to Million et al. (2003) about 71% of the farmers reported that careful application of sanitary control measures helps to control enset bacterial wilt disease. They also suggested that cultural practices such as deep tillage, exposing the soil during dry season prior to planting, proper spacing, spot rotation of infested sites to reduce disease spread. Avoiding overflow of water from infested to uninfested fields, controlling porcupine, mole rats and other domestic animals that may transmit the pathogen within the fields and surrounding areas (Mikias et al., 2010; Brandt et al., 1997; Shank, 1996) also help to minimize pathogen spread.

Use of clean planting materials (suckers/transplants, corms) and strict controls on the movement of planting materials from one area to other (developing local quarantine system) have also been well recommended for the management of enset bacterial disease (Brandt et al., 1997).

Other option for bacterial wilt management is the use of resistant or tolerant host plans. Farmers in different enset growing areas of the country cultivate different enset clones and claim that the clones show varying degree enset of susceptibility to bacterial wilt. In spite of this fact, owing to the perennial nature of plant, screening/breeding activities done on this plant in search of tolerant/resistant clone against the pathogen is scanty as compared to work done on cereal crops. However, Hawassa and Areka Agricultural Research Centers have been making concerted efforts in this regards. Areka Agricultural Research Centre has collected over 600 different enset vernaculars from different enset growing areas and maintained them at the Centre (Anonymous, 2009). Screening works done both at the Centre by artificial inoculation and in different farmers’ fields under natural disease conditions showed that “Maziya” enset clone has better resistance/tolerance than “Arkia”, which is highly susceptible check (Fikre and Gizachew, 2007). Developing tolerant/resistant enset clone needs further investigation of the genetic diversity of the plant in the country and this needs particular attention from the government side in terms of the human resource development and financial support.

No chemical trial has been conducted so far and there is no information regarding the use of chemical as an option for the control of enset bacterial wilt. Though biological control of bacterial diseases using microbial antagonists are known to be effective (Priou et al., 2006), this option has not yet been tried so far in the management of enset Xcmu.

In addition to what has been tried to manage/control enset bacterial wilt disease, continuous and uninterrupted public awareness creation program about the disease
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is mandatory. According to Karamura et al., (2008), “The battle against Xcm wilt needs to be multi-faceted, requiring mobilization of all available human as well as financial resources. Everyone must be aware and be committed to make sound contribution towards the control of the disease. All stakeholders need to be given clear/concise and appropriate messages, stating what needs to be done by whom, how, where and when so that they in turn could play their roles effectively”. It is therefore, unequivocal that concerted efforts be exerted in order to adjust the research strategy with the provision of adequate human and financial resources to effectively address the pathogen and with clear messages to the scientific and local communities for their unduly participation in such noble tasks.

Research Gaps and Recommendation
Since the time of first identification and official report of the pathogen (Xcm) (Yirgou and Bradbury, 1968), various research attempts have been made on some aspects of the disease especially on cultural and sanitary control measures. However, there are still some major research gaps that need to be addressed. The role of insect vectors, vertebrate pests (mole rates and porcupine), bats and domestic animals such as cattle in the transmission of the disease is not yet adequately investigated. The survival nature of the pathogen during fermentation of enset mass into primary food products and the role of the latter products in the transmission of the pathogen is not yet well determined. One of the major challenges is the lack of adequate knowledge of the epidemiology of the pathogen, which had been done only in such fragmented way. It needs to be conducted in a uniform hierarchical manner as its understanding is interlinked with the development of disease management options. Lack of sufficient knowledge on variability and/or similarity of the pathogen from all over the country are also another challenge. The taxonomy of the pathogen has not been resolved, it is still under discussion. The clear understanding of the taxonomy and its variability and or similarity would help in screening the local enset clones for developing resistant/tolerant clones as one management option. Although it has been claimed that huge enset vernaculars are known in the country, no sufficient work has been conducted on its genetic diversity. Characterization and classification of the existing local enset clones for their genetic diversity in relation to bacterial wilt disease and productivity should be supplemented with modern agricultural biotechnology. Lack of clean planting material has been considered as main source of disease spread over localities and hence this needs further attention in the future. Modern tissue culture techniques need to replace the cultural method of sucker propagation and provide farmers with disease free planting materials that would contribute to the battle against this deadly disease.

Owing to lack of effective control measures, farmers currently call this disease “enset AIDS” just similar to human HIV/AIDS which is not yet under effective medical treatment. Consequently, the management of this disease need to focus on prevention of disease transmission and spread. Eden-Green (2004) emphasized the use of control measures that reduce or prevent further spread of the disease to new
areas or areas that are not yet infected. Eden-Green indicated that the greater degree of control of this disease depends on prompt removal of sources of inoculum and/or reducing or eliminating opportunities for further spread. It is therefore important that the awareness of every stakeholder be raised at every level about this disease through different but effective campaigns. Everyone must know about the disease. Special attention should be given to areas that are not yet affected by the disease. The campaigns can be used to familiarize stakeholders with the disease symptoms and undertake effective phytosanitary practice as the only available control measure. Brandt et al. (1997) recommended for the use of healthy, disease-free suckers for planting material and destruction or complete removal of diseased plants as the best options for the control of enset bacterial wilt. To this effect, the establishment of national and local quarantine system is very essential. Quarantine measures can be re-enforced with bye-laws and other policy interventions, which in turn require appropriate institutional frameworks such as taskforce formation/ implementation and both human and financial resource commitments to make the system work (Karamura, 2008).

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Experience on Bacterial Wilt Management in Eastern Africa: The Case of Banana

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Abstract

Banana and plantains are among the most important crops in the world both as staple food and income generation crops. Enset, which is a banana like crop, is widely grown as a food source especially to the South and Southwest part of Ethiopia. A number of disease problems are recorded on banana, plantains and enset. Among others, Xanthomonas campasistris pv. musacearum is one of the devastating bacterial pathogen causing banana/enset wilt and lead to complete yield loss. In Uganda, research information that include incidence, distribution, economic importance, development of selective media, survival of the pathogen in the soil and banana debris, hosts range and management practices to be followed were generated which play a significant role in tackling this important disease of banana and plantain. The bacterial wilt pathogen of banana is also the causal agent of enset wilt. The purpose of this review is therefore, to compile experiences acquired/gained in banana bacterial wilt management in some other East African countries. Thus, the findings would help to extrapolate and adopt the management of enset bacterial wilt under Ethiopian condition. Therefore, this paper discusses the research and development experiences of East African countries, Ugandan experience in particular; on banana bacterial wilt management including available research recommendations, technology dissemination, task force formation and community mobilization through effective awareness creation and deployment of participatory development approach.

Introduction

Enset (Ensete ventricosum) is a relative of banana since both belongs to the family Musacea. However, enset is cultivated only in Ethiopia. It is a staple food crop for over 20 million people. Currently, it is dominantly grown in the southern and south western part of the country. It is expanding and growing in the northern part of the country. People in urban South of the country are well accustomed to the different types of food products of enset such as kotcho and bulla, which are made from enset through fermentation process are the two main forms of processed products used.

Banana and plantains (Musa spp.) (here after called bananas) is the fourth most important global food commodity in tropical and sub-tropical zones of the world. They are cultivated in over 100 countries covering about 10 million hectares, with
annual production of about 88 million tones of products (Sharrock and Frison, 1999). According to these authors, bananas and plantains provide more than 25% of food energy requirements for about 70 million people in Africa of whom 20 million are from East Africa alone.

In Uganda for example, banana supports over 70% of the population for food and income generation. Uganda has the world's highest per capita banana consumption at 220-460 kg per year (1.6 kg per person per day). It is second to India in production with 9.8 million metric tons per year (FAO, 1998).

One of the strongest characteristics of the crop is its unprecedented tolerance to drought. This makes enset as the most suitable commodity where currently the world is challenged with serious climate change and water deficit.

On the other hand, the most important production limiting factor of the crops is the banana bacterial wilt (BBW) caused by Xanthomonas campestris pv. musacearum. Full classical taxonomic description of the bacterium was given by Bradbury (1986). The objective of this review is to compile the experience of other countries on the management of Xanthomonas wilt, so that the findings or experiences of others could be adopted to the enset production system in Ethiopia.

**Research Experience**

The disease was first reported on enset in the 1960s in Ethiopia (Yirgou and Bradbury, 1968). It was later reported on bananas in the Keffa, Shoa, Sidamo, Hareruge and Gamogoffa regions of the country (Yirgou and Bradbury, 1974).

Lately in the year 2000, the disease was reported in Uganda affecting plantations of banana and plantains. Currently, the disease is reported from 36 districts (out of 58) in Uganda. New outbreaks have also been reported in Rwanda (Reeder et al., 2007), in the Democratic Republic of Congo (Ndungo et al., 2005), Tanzania (Mgenzi et al., 2006a, 2006b), Kenya and Burundi (Smith et al., 2008).

Various survey reports conducted since 2001 in Uganda indicated that in all the affected districts, all banana types [(Pisang awak ABB), Blugoe, Highland bananas (AAA-EA), Gross Michael and Neypoovan] were affected. Consequently, in one year 70 - 80% incidence was reported for many affected plantations.

Since the occurrence of bacterial wilt in Uganda in 2000/1 intensive research undertakings were considered and more than 15 research articles were published about the various aspects of the disease in such short period of time.
Basic research

The classical taxonomic description (Brandbury, 1986), complementary fatty acid and molecular information of the pathogen were generated (Tushemereirwe et al., 2004 Aritua et al., 2008). Diagnostic molecular tools such as PCR primers developed for identification and detection of the pathogen (Aritua et al., 2007a & b).

The results of the studies conducted in Ethiopia indicate the occurrence of low levels of genetic variation between strains of X. campestris pv. musacearum, collected from the first outbreaks and recent outbreaks were also observed in other countries (Aritua et al., 2007). They also indicated that DNA sequencing studies have also shown that the species are closely related to X. vasicola.

New semi-selective media was developed for artificial multiplication of the pathogen. The semi-selective media designated as CCA contains 1g yeast extract, 1g glucose, 1g peptone, 1g NH4Cl, 1g MgSO4.7H2O, 3g K2HPO4, 1g beef extract, 10g peptone, 14g agar, 40mg cephalaxin 10mg 5-fluorouracil and 120mg cycloheximeide). With this media it was possible to recover 82% of the target bacteria from soil compared to the standard media (yeast peptone glucose agar /YPGA/ containing 5 g yeast, 5g peptone, 4g glucose, 12g agar per liter), which gave only 42% (Mwebaze et al. 2006a).

Investigations were made to determine the survival of Xanthomonas campestris pv. musacearum in soil and infected banana debris. The pathogen persisted longer (two times) in high moisture conditions (28%) than in low moisture soil conditions (14%). The pathogen populations declined rapidly in non-sterile soil (only 15 days) than in sterile soil (90 days). The pathogen could not persist in sterile moist soil for a period longer than 90 days and 30 days in dry soils and its survival period in the field was longer in the soil than in banana debris (Mwebaze et al., 2006b). However, the population of the pathogen in banana debris in the field declined rapidly while the decline was gradual in the laboratory. Viable cells of the pathogen could not be recovered from plant debris incorporated in soil or on soil surface of banana debris after 21 days. Therefore, according to the same authors, the disease causing bacterium, X. campestris pv. musacearum survived in the absence of a host for only 20-90 days depending on the environment.

Studies were made to determine the survival of bacterial cells on metallic tools through smeared onto blades and survival was monitored for over 72 hours by checking growth of colonies on bacterial culture media. Xanthomonas remained viable and infective for the entire 72h period. Therefore, the results proved that bacteria remained viable for extended periods of time and provided evidence to support the recommendation given to farmers to disinfect their tools regularly to avoid disease transmission.
Moreover, the reaction of 42 local banana genotypes to *X. campastris pv. musacearum* was tested and there was no significant difference among test materials. Among the germplasms, 5 were natural diploids, 15 natural triploids, 10 hybrid diploids and 12 hybrid tetraploids. They were tested for their reaction to *X. campastris pv. musacearum* at the age of three months in Uganda. All were found susceptible except *M. balbisiana* (natural wild type), which showed some resistance reaction (Sskiwoko et al., 2006a). Although, the disease had been observed in Eastern Highland bananas and exotic dessert and beer bananas, the clones varied in the incidence of the disease (Tushemereirwe et al., 2003). Disease incidence was highest on Kivuvu (73.5%), followed by Kayinja (30.4%) then cooking bananas (11.7%) and the least (2.8%) was in Sukari Ndizi (Tushemereirwe et al., 2003).

The banana parts such as fresh leaves, dry leaves, fresh pseudo-stem, sheath, fruit peelings and corms picked from diseased plants were used to inoculate plantlets. Inoculations with fresh banana parts, in particular, were able to cause disease incidence between 5 - 20% to healthy potted banana plantlets only after wounding the test plant roots. Bacteria were more abundant in fresh leaves and least in dry leaves (Table 1). The number of bacteria cells isolated from banana corms, fresh leaves, fruit peeling and pseudo-stem sheaths were similar. More than 75% of bacterial isolates suspected to be the banana wilt bacterium that were isolated from the different banana parts were pathogenic to banana plantlets (Table 1). Therefore, practices that involve movement of fresh banana parts should be discouraged to avoid plant materials that could carry viable and pathogenic bacteria (Tumushable et al. 2006).

Using dried leaves did not cause any wilt symptom, though isolation of the pathogenic bacterium was possible. However, none of these infected dried parts affected any plant whose roots had not been wounded indicating that wounding seems to be a prerequisite for infection in this case (Tumushable et al. 2006).

<table>
<thead>
<tr>
<th>Plant parts/ treatments*</th>
<th>Log10 (bacteria cells/g plant tissue +5)</th>
<th>Pathogenic isolates (percentage)</th>
<th>Incidence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corms</td>
<td>9.65±0.89ab</td>
<td>79 (n=8)</td>
<td>6.7 (n=15)</td>
</tr>
<tr>
<td>Dry leaves</td>
<td>7.59±0.46b</td>
<td>82 (n=20)</td>
<td>20 (n=15)</td>
</tr>
<tr>
<td>Fresh leaves</td>
<td>10.35±0.95a</td>
<td>100 (n=9)</td>
<td>0 (n=15)</td>
</tr>
<tr>
<td>Fresh pseudo-stem sheath</td>
<td>9.73±1.02ab</td>
<td>93 (n=7)</td>
<td>13.3 (n=15)</td>
</tr>
<tr>
<td>Fruit peelings</td>
<td>9.62±0.89ab</td>
<td>90 (n=9)</td>
<td>13.3 (n=15)</td>
</tr>
</tbody>
</table>

Source: Tumushabe et al., 2006; *part of plants obtained from diseased plant

Means with the same letter within the column are not significantly different at 0.05 level of probability by pair-wise t-test of test of least square means.
Host range test was done using three categories of plants, i.e. 1. Wild banana relatives (Musa ornate and M. zebrina), 2. Ornamentals/weeds/banana intercrops (Canna indica, Heliconia metallica, Ageratum conyzoïdes, Commelina sp., Bidens pilosa, Ananas comosus, Zingber oficinale, Ipomio batatus, Lycopersicon esculentum, Datura stramonium, Capsicum spp., Galinsoga pervaflora, Elettaria cardamomum) and 3. Species that are hosts to Xanthomonas campastris group (Manihot esculentum, Pennisetum purpureum, Saccharum oficinale, Amaranthus dubius).

Typical symptoms were visible on plants species Musa ornate, M. zebrina and Canna indica inoculated with X. campastris pv. musacearum. There were no symptoms observed on other tested plants (Ssekiwok et al., 2006b).

Tripathi and Tripathi (2009) evaluated 10 cultivars of banana by injecting bacterial inoculum in pseudostem of in vitro plantlets and potted plants. Pisang Awak, Dwarf Cavandish, Giant Cavandish and FHIA-17 were highly susceptible; Mpologoma, Mbwazirume, Sukali Ndiizi and FHIA-25 were susceptible while Nakitembe was least susceptible. Musa balbisiana was found resistant (Tripathi and Tripathi, 2009). Apparently, all commercial cultivars are found susceptible to the pathogen.

Insects found on banana inflorescence are possible sources of inoculums in banana plant. Insect species that carried the bacterium on their bodies were determined as possible vectors of the disease (Tinzaara et al. 2006). The most abundant insects visiting banana flowers are stingless bee (Plebeina denoiti (Vachal) (Aphidae), fruit flies /Drosophilidae/ and grass flies /Chloropidae/. Female flowers had twice as many insects as male flowers (Table 2). The bacterial cells have been isolated from the stingless bee /P. denoiti/, honey bees (Apis melifera), fruit flies and grass flies that had been collected from male flowers of both asymptomatic and symptomatic plants. The bacterial cells isolated from P. denoiti were more than two times as many as other insect groups (Table 3). Moreover, insects generally visited during the entire day with the peak visitation from about 12.00-2.00 (Tinzaara et al., 2006).

Table 2. Number of insects visiting female flowers/asymptomatic and symptomatic of infected and non infected banana fields

<table>
<thead>
<tr>
<th>Enset Family</th>
<th>Common name</th>
<th>Infected banana fields</th>
<th>Non-infected banana fields</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Asymptomatic</td>
<td>Symptomatic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Plebeina denoiti (Aphidae)</td>
<td>Stingless bee</td>
<td>39.4±4.1</td>
<td>34.1±2.9</td>
</tr>
<tr>
<td>Undetermined species (Aphidae)</td>
<td>Stingless bee</td>
<td>2.8±0.5</td>
<td>2.6±0.3</td>
</tr>
<tr>
<td>Melipona sp. (Aphidae)</td>
<td>Stingless bee</td>
<td>1.0±0.5</td>
<td>1.7±0.3</td>
</tr>
<tr>
<td>Apis melifera (Aphidae)</td>
<td>Honey bee</td>
<td>3.6±0.6</td>
<td>3.3±0.5</td>
</tr>
<tr>
<td>Undetermined species (Chloropidae)</td>
<td>Grass flies</td>
<td>2.8±0.4</td>
<td>3.7±0.6</td>
</tr>
<tr>
<td>Undetermined species (Aphidae)</td>
<td>Fruit flies</td>
<td>14.1±4.1</td>
<td>9.3±1.6</td>
</tr>
</tbody>
</table>

Source: Tinzaara et al., 2006
Table 3. No. (±s.e) of *Xanthomonas campesiris pv. musacearum* colonies isolated from insect vectors collected from asymptomatic and symptomatic flowers of the cultivar Kayinja

<table>
<thead>
<tr>
<th>Enset family</th>
<th>Common name</th>
<th>Mean no. of cfu per insect</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pteboina denoiti</em> (Aphidae)</td>
<td>Stingless bee</td>
<td>1645±1197 (3)</td>
</tr>
<tr>
<td>Undetermined species (Aphidae)</td>
<td>Stingless bee</td>
<td>2637±977 (5)</td>
</tr>
<tr>
<td>Undetermined species (Chloropidae)</td>
<td>Grass flies</td>
<td>2543±1963 (7)</td>
</tr>
<tr>
<td>Undetermined species (Drosophilidae)</td>
<td>Fruit flies</td>
<td>1647±1197 (3)</td>
</tr>
<tr>
<td><em>Apis melifera</em> (Apidae)</td>
<td>Honey bee</td>
<td>5058±3275 (6)</td>
</tr>
</tbody>
</table>

Source: Tiunara et al., 2006;

A study was also carried out to estimate the economic value of the likely loss due to banana bacterial wilt (BBW) if not controlled and the potential of implementing the short term control. If BBW is not controlled, Uganda stands to lose an estimated 295 million dollars worth of banana output valued at farm gate prices. This translates into an annual 200 USD (Table 4) of food and income per household at stake (Kalyebara et al., 2006).

Table 4. Estimated annual economic losses with and without intervention

<table>
<thead>
<tr>
<th>Year</th>
<th>Loss if BBW is not controlled (USD 2005)</th>
<th>Loss if ABCC is adopted (USD 2005)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2001</td>
<td>2506660</td>
<td>2732612</td>
</tr>
<tr>
<td>2002</td>
<td>4509878</td>
<td>4563088</td>
</tr>
<tr>
<td>2003</td>
<td>13512297</td>
<td>13600690</td>
</tr>
<tr>
<td>2004</td>
<td>30108824</td>
<td>30419187</td>
</tr>
<tr>
<td>2005</td>
<td>137605308</td>
<td>129510853</td>
</tr>
<tr>
<td>2006</td>
<td>204532511</td>
<td>159306130</td>
</tr>
<tr>
<td>2007</td>
<td>274388276</td>
<td>168336522</td>
</tr>
<tr>
<td>2008</td>
<td>365611044</td>
<td>198109127</td>
</tr>
<tr>
<td>2009</td>
<td>453769274</td>
<td>251619347</td>
</tr>
<tr>
<td>2010</td>
<td>689802425</td>
<td>366013547</td>
</tr>
<tr>
<td>2011</td>
<td>605826477</td>
<td>321455376</td>
</tr>
<tr>
<td>2012</td>
<td>532073689</td>
<td>282321678</td>
</tr>
<tr>
<td>2013</td>
<td>467299501</td>
<td>247952083</td>
</tr>
<tr>
<td>2014</td>
<td>410410866</td>
<td>217766612</td>
</tr>
<tr>
<td>2015</td>
<td>360447804</td>
<td>191255894</td>
</tr>
<tr>
<td>2016</td>
<td>316567202</td>
<td>167972568</td>
</tr>
<tr>
<td>2017</td>
<td>278028566</td>
<td>147523733</td>
</tr>
<tr>
<td>2018</td>
<td>244186127</td>
<td>129564322</td>
</tr>
<tr>
<td>2019</td>
<td>214455168</td>
<td>113791274</td>
</tr>
<tr>
<td>Total</td>
<td>5,605,637,416</td>
<td>3,144,814,644</td>
</tr>
<tr>
<td>Average</td>
<td>295,033,548</td>
<td>165,516,560</td>
</tr>
</tbody>
</table>

Source: Kalyebara et al., 2006

Means of disease transmissions are mainly through male flower buds by pollinating insects, bats and sunbirds. Other means of transmission are use of contaminated
planting materials and cutting tools, browsing animals and water when it moves around infected soils.

Taxonomic similarity of *X. campastris* pv. *musacearum* to *X. vasicola* pv. *musacearum* was mentioned. Some authors renamed the pathogen to *X. vasicola* pv. *musacearum*. If this is to be true, then scientists need to establish the host ranges especially of maize, sorghum and sugar cane.

**Disease Management**

There are two key pillars of actions in combating BBW. These are first promptly removing sources of inoculums and reducing opportunities of spread. Cutting down and heaping diseased plants as a way of eliminating inoculums. Since this is tedious and cumbersome, systemic herbicides like glyphosate and 2,4-D were tested using five concentrations to determine the one that is more effective in destroying infected banana plants. All plants injected with 2, 4-D herbicide snapped and died within 30-40 days while with glyphosate it took 90 to 120 days (Okurut *et al.*, 2006). Both herbicides were able to kill at least 85% of the plants. Besides these, herbicides dose, material size and nature of suckering was studied. Resuckering rates between both herbicides did not significantly differ. The resuckering for 2,4-D were 11.3% and 7.2% at station and farmers’ field while for glyphosate 15% and 1.5% were the values for on station and farm, respectively. Herbicides were able to destroy plants within radius of 16.8±1.76 cm from injected plant/mat. Higher dose killed better and earlier, but caused higher resuckering. In Uganda, based on environmental safety, glyphosate is recommended for farmers use.

The disease causing bacterium, *X. campastris* pv. *musacearum* survives in the absence of a host for only 20-90 days depending on the environment (Mwebaze *et al.* 2006). It is recommended to suspend pruning, corm removal, ploughing and leaf harvesting and resume these activities only after the disease has been cleared (3-6 months after the last diseased plant). The use of tools when removing infected plants or harvesting and utmost care not to infect other plants (clean the tool every after a plant harvested) are recommended routine practices.

Works are under way to develop resistant banana varieties through genetic transformation (both Agrobacterium-mediated transformation and microprojectile bombardment) (Tripathi *et al.*, 2008).

**Development and Implementation of Control Strategy**

In Uganda, task force was established to develop a strategy and action plan to eradicate the disease. The strategy emphasized massive creation of awareness, cutting and burying infected banana stools, quarantine, decapitation of male buds,
and disinfection of farm tools used in the affected fields. Such quick measure reduced disease incidence below 10% per year, but could not be sustained due to high implementation costs. Consequently, the disease was reported in more districts necessitating a change of strategy and hence the National Agricultural Research Organization (NARO) was directed to develop a comprehensive research and development strategy from eradication to contain and manage the disease.

**Establishment and coordination of the banana bacterial wilt control initiative (BBWCI)**

Technical committee from Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), NARO, Mekerere University, local government and International Collaborating Institutions was formed and charged with the task of guiding implementation of the activities for control of the disease. A National Coordinator to spearhead the efforts to control the disease was appointed and tasked to coordinate all activities on BBW control in the country as one entity known as the National Banana Bacterial Wilt Control Initiative (BBWCI).

The BBWCI was charged with responsibility to ensure that all institutions, that have banana in their activity portfolio, integrate BBW control in their action plans. To strengthen coordination and monitoring of BBW control activities, a system of task forces was provided for at various local government levels. It was envisaged that the National Coordination System, with the National Steering Committee (National Task Force) as its apex, would link to the farming communities in villages through district task forces, sub-county task forces, parish task forces and finally village task forces. Such arrangement would ensure participation of all stakeholders in control of the disease. The activities of BBWCI at district, sub-country, parish and village levels would be coordinated by public extension staff with task forces at the different levels playing the monitoring and overseeing roles at their respective levels.

With the BBWCI structure in place, teams simultaneously embarked on activities aimed at containing and controlling the disease as well as monitoring the impact of the efforts.

**National sensitization campaign for control of the disease**

The BBWCI set priorities to enable most effective use of the insufficient financial resources available to it.

- Highest priority was accorded to the disease free/threatened zone where plantations needed protection from the disease. Pockets of disease outbreak were anticipated and the goal of the initiative in these areas was to eradicate disease outbreaks.
- The second priority was halting further advance of the disease frontline zone (the advancing edge of the disease endemics) - main producing region in the country. The goal of the initiative was to push the endemic zone backwards by eradicating the disease in affected plantations in the frontline.
• The third priority was ranking zones where the disease was considered endemic. As the short term objective of this initiative was to enable farmers to cope with the disease with ultimate goal of eradicating the disease from farmers' fields.

The initiative deployed both conventional communication methods ideal to reaching wide audiences and participatory communication methods and initiating action at community level. The sensitization campaign involved raising stakeholders’ awareness about the disease and its control through trained trainers and multiple communication channels. The conventional communication approaches deployed are:

**Multiple communication channels:** BBWI produced and distributed 40000 posters in 2004 as well as 67000 brochures, 100000 newspaper inserts and 6000 calendar posters in 2005. Radio spot messages and talk shows were done in five different languages. The campaign was scaled up in the first half of 2006 with the production of 100000 refined posters, radio spot messages and talk shows in ten languages on 18 local radio stations and 10000 brochures targeting extension workers. The use of bill boards and school poster package were also piloted.

• **Trained trainers:** Two hundred and ninety six extension workers all drawn from the three zones were trained on identification and control of BBW in preparation for deployment as trainers in 2004. Additionally, 148 service providers drawn from the National Farmers’ Foundation were trained in 2005 to support the trained extension workers.

• **Seminars and workshops:** Several seminars and workshops at district and grass root levels were conducted by trained trainers. These enabled the many local leaders, opinion leaders, NGOs, and interested farmers to join the expanding pool of trainers.

• **Public gatherings:** Going at social gatherings such as religious occasions, funerals gatherings, political rallies and markets etc was founded instrumental in spreading information about BBW and tracking down its progress. The technique was mostly used in the unaffected areas to track the disease outbreaks.

The information from farmers and task forces in affected areas was channeled to the coordination office through their local government extension workers. The BBW control team made on-spot checks for each of the new areas where the disease was reported and mobilized the local leaders to set up task forces for containing and controlling the disease using a participatory approach.

**The BBW Control Recommendation Packages**

• Avoid introducing the disease into any area, garden or unaffected plants. Avoid using tools in the plantation until all are disinfected, or sterilized before using them. This prevents stool to stool spread of the disease through the tools; restricting entry of infected bananas or banana parts into any area/garden.
• Break male buds from all banana plants at about two weeks after flowering with a forked stick. This will prevent disease transmission by insects which visit the flower. Using a stick therefore, prevents transmission that would otherwise be transmitted by cutting tools.

• Clear all disease plants by uprooting and heaping or using 'roundup' (glyphosate) herbicide as recommended by the BBWCI at the rate of 1 ml product/banana mat. This eliminates source of inoculums.

• Clean tools used to clear infected plants by briefly heating them with fire flame or dipping them in a "Jik" (sodium hypochlorite solution) in 1- 5 water to Jik ratio. Cows and goats should not be fed on diseased plants or be allowed to pass through banana plantation, as these mechanically spread the disease from infected plants to healthy plants (through feeding on the plants).

• If freshly diseased plants are not observed for 3 to 6 months, resume using the tools in the banana plantation. However, it is advisable to remain vigilant as fresh infection is highly likely to occur.

Community action, in the form of bylaws and working together, is important to mobilize errant farmers who do not want to implement recommended control measures. The public stands to lose when these errant farmers are left alone, and therefore the problem needs to be addressed by public action.

The conventional top-down approach was instrumental in swiftly raising awareness of stakeholders about the disease across the whole country, but was not effective in triggering actions aimed at controlling the disease. Therefore, participatory development communication (PDC) approach was formulated and deployed which was effective previously in Canada (Bessette, 2004). This approach centers on action plans developed by communities to address specific problems facing them. A development worker trained in this approach facilitates the community to develop the action plan.

• The approach was introduced to community leaders to get buy-in as foundation for full implementation and scaling out.

• Community members, their leaders, development workers and researchers were brought together to share information on the BBW and other banana management problems. It ended with the farmers identifying strategies they wished to try to solve the BBW problem (prevention if farmer had unaffected plantation, or eradication measures if plantation is affected).

• Community members were grouped on the basis of the strategies applicable to their BBW situation (protecting unaffected gardens or eradicating the disease)

• Each group identified actions required to implement the solution to be tried, resources required, technical needs, partnerships required and who would do what

• Each group developed a communication plan to eventually enable them share lessons learned with the wider community if their efforts paid off.

• Finally, the community developed a monitoring and evaluation plan, a schedule of activities and agreed on how to source for required resources.
The plan was then implemented and the success story created at this site was shared with wider community through various communication channels and released at a massively attended open day presided over by MoAAIF. The community action plan strategy was scaled out to new areas through a training of trainers approach as is done in conventional extension approach.

**Gaps/Challenges to Fully Implement Cultural Practices**

Unfortunately, farmers are generally reluctant to cut off male buds especially on Kayinja and Kivuvu. Farmers have advanced various reasons for not cutting off the male buds. Some reported that they wanted to use the male buds to identify affected bunches so that they do not harvest them for consumption. Some noted that it is in their tradition not to remove male buds from Kayinja because the practice reduces the quality of alcohol produced from such bunches. Others just found it tedious to go through Kayinja plots to remove the male buds (Bagamba et al., 2006).

**References**


Yirgou, D. and Bradbury J.F. 1968. Bacterial wilt of enset (Ensete ventricosum) incited by Xanthomonas musacearum sp.n. Phytopathology 58, 111-112.

Regional Strategy for Banana/Enset Bacterial Wilt Management in East Africa: The Road Map for the National Action Plan

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Abstract

Bacterial wilt (Xanthomonas campestris pv. musacearum) has continued to threaten enset and banana production in East Africa, endangering the livelihoods of poor, small-holder farmers. Many countries now regard it as a major priority constraint to banana production, overtaking weevils, nematodes, and fungal and viral diseases, for which farmers applied cultural practices that affected the differences in cultivars’ resistance/tolerance on farm. These way farmers suffered in reduced productivity, but maintained a reasonable level of food and income security. However, with the arrival of banana bacterial wilt in the region, entire crop holdings were wiped out in some areas, where highly susceptible genotypes were dominating the farming systems. It is not yet established how the disease “spread out” of the Ethiopian highlands into the mid-altitude regions of East and Central Africa, where the disease reportedly causes 80-100% crop loss especially in ABB beer bananas in Uganda and Democratic Republic of Congo (DRC). Previous efforts to control the disease produced partial solutions and the disease has continued to invade previously disease free areas and to resurge in areas where it had been controlled. Current control strategies are facing major challenges including the inability to detect latent infection (in planting material and other enset/banana products), the user-unfriendliness of some recommendations such as flame and chemical decontamination of implements; lack of genotypes resistant to the disease and lack of coherent institutional frameworks for organizing and mobilizing stakeholder partnerships within and between countries, to exploit stakeholders’ synergies at local, national and regional levels.

Introduction

The communities of the East African plateau (Western Kenya, Uganda, North-western Tanzania and Eastern D R Congo) have traditionally depended on a perennial banana cropping system for food and income. This farming system is a slow-changing and rural-based economy that has ensured regional food security for many centuries. In recent decades, this system has come under stress, with decreasing farm size, decreasing fallow periods and production progressively, unable to meet household needs, leading to increased inter-communal tensions. In
the coming decades, the sub-region may face additional stresses, including climate change, characterized by increasing temperatures and greater rainfall variability, plus changing social structures due to HIV-AIDS, rural-to-urban migration and declining returns from agriculture. Until the beginning of the century, the main biotic threats (weevils, nematodes, fungal and viral diseases) were managed via cultural practices exploiting differences in cultivars' resistance / tolerance on farm. In this way farmers suffered reduced productivity, but maintained reasonable levels of food and income security. However, following the arrival of enset and banana Xanthomonas wilt (BXW) (Xanthomonas campestris pv. musacearum) in the region, entire crop holdings were wiped out in some areas, where highly susceptible genotypes were dominating the farming systems. Until the 1960s, the bacterial wilt had been known only in Ethiopia, in both bananas and enset.

In 2001, the disease was reported simultaneously in Central Uganda and in North Kivu province of D R Congo and a year later in North-western Rwanda. Between 2002 and 2006, the disease spread to the major banana growing regions of Uganda, Western Kenya, and other countries in Central Africa, where it caused 80-100% crop loss especially in beer bananas in Uganda and D R Congo. BXW continues to seriously threaten enset and banana production in the region and sustainable wilt-disease control measures must be implemented, to avoid further devastation.

**Regional Distribution of *Enset*/*Banana* Bacterial Wilt**

Bacterial wilt is currently restricted to Africa. The first report of *X.campestris pv.musacearum* causing a wilt on Musaceae is on enset in Ethiopia (Yirgou and Bradbury, 1968) with the disease reported as being present in many enset-growing localities in Central and Southern Ethiopia. However, the bacterial wilt of enset with symptoms consistent with *X.campestris pv musacearum* was described previously in the late 1930s. Subsequently, *X.campestris pv musacearum* as a pathogen of banana was first described in Kaffa province and later in warm, moist areas of other provinces in Ethiopia (Yirgou and Bradbury, 1968). *Enset* is banana like plant on which approximately 20% of the Ethiopia's population depends for food, feed and fiber (Tsedeke et al.,1996) The occurrence of the disease on banana was a less common crop at that time. Surveys conducted on enset wilt incidence in 24 different localities in 1997/98 and 1998/1999 crop seasons indicated that the percentage incidence was highest at Gera and Suntu in 1997/1998, while in Waka, Gera and Solemo the incidence was high only in 1998/99 seasons (Abraham, 2009).

*Xanthomonas* wilt was first reported in Uganda in Mukono district of Central Uganda in 2001 (Tushemereirwe *et al.*, 2004; Karamura *et al.*, 2006). By 2006, it was confirmed in 35 districts in all regions of the country. It has now been reported in 319 sub-counties out of a total of 986. It is said to be 'endemic' in 244 sub-counties with
spread contained or controlled in 70 sub-counties. The experience in managing banana bacterial wilt some African countries is presented in brief.

**Democratic Republic of Congo**

Banana *Xanthomonas* wilt was first observed in 2001 at Bwere, in the North Kivu Province bordering Uganda and Rwanda two years before it was officially recorded. Since then, the disease has been spreading consistently in all directions from Bwere, gaining about 5km per year. A second outbreak was discovered in 2003, 10 km from Bwere, with the same spread pattern.

Bananas represent the main staple food in North Kivu. Prior to the disease infestation in the region, 70% of the cultivated land was occupied by bananas, generating 60% of household income. A survey conducted in the Bwere region indicated that the BXW outbreak has caused complete failure of banana harvests in most farmers’ fields. Yields have declined from 20 t/ha/year to almost zero with a corresponding income loss of about 1600 $/ha/year (Karamura E et al, 2006).

*Wilt enset* is affected in Congo, supporting the idea that the disease is related to the bacterial wilt in Ethiopia. Among the cultivated bananas the disease mainly affects Kayinjas, Ndizi, plantains, EAHB and Cavendish in that order. The symptoms observed usually involve yellow discoloration of the stem, yellowing and dying off of the leaves, yellow ooze and discoloration of the fruit. Farmers believe that the infection gets into the plant through the leaves or flowers and continues down to the stem and corn.

Movement of the disease has been associated with the lakes and there is a suspicion that migrating birds that regularly visit the lake shores may be involved with the introduction of the disease to the region. It is also suspected that leaf-feeding insects are involved in disease spread. In affected areas, the farmers are losing hope. Strict sanitation measures are under adoption, including chopping the pseudo-stem into pieces and leaving them to dry.

**Kenya**

Banana is a major crop in Kenya covering 74,000 hectares (2% arable land) and over 1 million t/year are produced. The Ugandan Phytosanitary Department informed Kenya when BXW broke out in 2001. Scouting surveys were later conducted in Western and Coastal regions of Kenya in September and December 2004. This was followed by deploying interviews and transect walks, and collecting samples. BXW was not encountered but a range of other pest and disease problems (Weevils, Fusarium wilt, Sigatoka etc.) were observed. It was also noted that bananas are imported from Uganda and Tanzania and marketed in major towns in Kenya. The introduction of the disease into Kenya was likely through plant materials.
A number of actions have been taken since the scouting surveys, including stepping up border inspections, instituting a system of import permits to control and monitor cross-border movement of banana materials and products, issuing phytosanitary certificates for bananas entering Kenya; banning sucker importation (except tissue cultured materials under quarantine), intensifying information exchange with Ugandan counterparts (two plant inspectors visited Uganda to familiarize themselves with the disease), instituting regular communication with stakeholders about the threat of the disease; and certifying nurseries distributing banana seedlings.

Tanzania

*Xanthomonas* wilt was first detected in September 2005 by farmers in Kabale village of Izigo division within Muleba District, which is in the Kagarea region bordering Lake Victoria, Uganda, Rwanda and Burundi. In January 2006, the outbreak was confirmed as *Xanthomonas* wilt and symptoms were also seen in nearby Kabale B sub-village. Plants in Izigo, Kikondo, Bumilo, and Magata villages in Maruku district were also affected. The scattered outbreaks were separated from each other by tens of kilometers. It was estimated that banana plants belonging to about 100 households had the disease. Spread from Eastern Rwanda was suspected, although there were no reported out breaks in this area at that time.

Uganda

**Managing Banana Bacterial Wilt**

Banana is a very important food and cash crop supporting over 70% of the population of Uganda. Production in all year round reaches a potential yield up to 60 t/ha/year. The crop, therefore, has high industrial potential. It has however, been constrained by a number of factors:

In the implementation of the national action plan, a number of challenges have been encountered. These include the shortage of resources to implement priority activities, the mobilization of key stakeholders along the production-consumption chain (e.g. central and local governments, development partners, community leaders, faith-based organizations, NGOs and farmers) to support the control efforts and the weak linkage between research and extension. At the farm level, the initiative has met challenges posed by traditionally low levels of adoption of agronomic practices in affected areas and negative attitudes towards implementing some of the recommended practices such as sanitation based husbandry. These challenges however are being addressed through participatory approach and awareness campaigns.

**Community Approaches in Managing BXW**

**Participatory development communication (PDC)**

Farming communities were directly targeted using a participatory development communication (PDC) approach. This approach involves members of the
community to take part in problem identification and analysis, and enables the community to analyze and explore alternative solutions to the problem and to identify the best solutions which they are ready to implement. PDC helps to know why some members in the community don’t implement some control measures and to identify the constraints that they face in implementing control measures. Using community knowledge, researchers are able to develop technologies more effectively. The model was tested in three BXW-affected zones. Stakeholder planning workshops also took place involving agricultural extension staffs from district and sub-county levels, political leaders (Local Council levels 1 - 3); educational institutions, schools, cultural and religious leaders, NGOs, CBOs and farmers.

The workshop participants identified and prioritized banana-related community needs and constraints and agreed on technologies to address them. Through PDC, interactive discussions identified IPM and BXW problems (pests, diseases, soil fertility, banana cultivars, etc.) and agreed on solutions, including field demonstrations to show BXW symptoms, transmission and control measures. Subsequently, the information acquired was used to develop community BXW action plans to be executed by task forces at various community levels.

In the execution of PDC, a number of challenges emerged. Participants had diverse perceptions about the cause of BXW (including deliberate introduction by scientists, exotic bananas, tissue culture plants, degraded soils, and Mulinga tree, use of molasses in banana systems, etc.). They also discussed reasons why some people in the communities did not implement the recommended control measures. The reasons given included ineffective measures, labor intensive measures, laziness, lack of effective alternatives, costly disinfectants, miscommunication from neighbors, researchers who wanted to eliminate traditional technologies, negative attitudes towards technologies, contradictory messages, and fear that new cultivars might degrade the soil.

The PDC’s interactive approach enables farmers, who were ignorant of basic crop management and IPM practices to take advantage of the extensive experience of other farmers. Community leaders, having been made fully aware of the threat, pledged to support the effort to fight the disease, and it was recognized that the responsibility of the BXW problem has to be shared by the whole community.

Community organizational framework

In Uganda, the community task forces, consisting of four people, mobilized individual communities in partnership with parish and village councils, trained people on BXW, directed the development and implementation of community actions plans, and monitored and communicated progress to the task force at the next community level. The task force was also responsible for the establishment of
demonstration plots and maintaining networks with other partners in control of BXW (agric-extension, NGOs, NARO, MAAIF and others). Training videos in different languages were used to disseminate information on BXW symptoms, transmission and control, PDC methods, the sensitization process and success stories of BXW control in model districts. Fact sheets on BXW symptoms, transmission and control; guidelines for formation of BXW task forces in the community; posters and brochures on BXW; and banana production manuals were also disseminated.

The experiences gained from the initial PDC model in the pioneer areas were used to scale out activities to other areas. The original model was slightly modified in order to gain more political backing and funding support, by targeting the Chief Administrative Officer and the Local Council chair person at the highest level in the district rather than the District Agricultural Extension (DAE).

The Regional Strategy for Managing *Enset/Banana* Bacterial Wilt

The disease outbreak in Uganda was reported in 2001. Since then the Banana Research Network for Eastern and Southern Africa (BARNESA) Steering Committee had rated BXW as a top R4D priority and has taken steps to coordinate regional efforts aimed at alleviating the impact of the disease on the livelihoods of the affected communities. In this regard, INIBAP-BARNESA has coordinated a multi-institutional, multi-stakeholder study (funded by the DFID-UK and IDRC-Canada) to assess the impact of BXW on the livelihoods of communities along the production consumption pipeline, and to understand how the communities are coping with the disease. In addition, INIBAP in collaboration with the FAO is convening a number of regional and international meetings to develop plans for addressing the problem. This strategy was developed from the recommendations of a regional workshop held in February 2005. It is envisaged that the involvement of international, regional, national and local level actors and interventions to coordinate and bring synergy into research and extension efforts and to support farmers and communities in ‘people-focused’ activities.

In the short-term, the strategy aims to generate and disseminate robust, diagnostic tools that facilitate disease recognition, management and control. In addition it envisions a program for spatial surveillance to monitor what is happening where in the region and a regularly-updated portal for information sharing. At all levels of the production-consumption chain, capacity must be strengthened. All activities will need to be coordinated and monitored to ensure that corrective measures are taken in time.

In the medium term, a regional impact tracking mechanism that regularly generates and packages information products for policy makers will be put in place and integrated into the overall regional strategy for integrated pest and disease management. Regional policy dialogue should be strengthened to allow the
coordination and management of trans-boundary epidemics to food security and household incomes. In the long term, a systems approach should be adopted to boost the health of farming systems, taking full account of genetic diversity, the resource base and biotic stresses. Grass-roots ownership and sustainability should be ensured by deploying a livelihoods approach to improve prospects for marketing bananas and banana products. Indigenous germplasm threatened by the disease must also be effectively conserved in perpetuity to ensure that farmers can replant traditional genotypes once the effects of the epidemic have lessened.

This strategy regional approach to address bacterial wilt of enset/banana is based on essential learning, from within and outside the region, gained from successfully controlling other bacterial wilt diseases, and itself a model of regional response to a disease epidemic. Such a strategic and comprehensive approach has the potential to bring the disease epidemic in the East and Central Africa under control and prevent its further spread. However, its success depends on the ability of the diverse partners in this effect to mobilize resource and government support to reach communities throughout affected areas and beyond- and then to ensure commitment to disease management campaign and good practice in the longer term.

Ethiopia

Important issues to be considered in designing the road map for national action plan

In designing the road map, the strategy should underpin the importance of integrating gender, poverty and environmental conservation considerations based on the Millennium Development Goal. MDGs are therefore well placed in the national development context of the country. In line with the objective of poverty eradication and bringing about social development, the Government of Ethiopia has invested in both physical and human capital formation which could be considered as best practice to address the challenges of achieving the MDGs (MDGs Report, 2010). Nonetheless, the following elements of activities need to be considered in order to draft the action plan for integrated management of banana/enset bacterial wilt control in Ethiopia.

- Collection of the baseline information: This includes covering disease severity, farmer perceptions and coping measures being implemented; the establishment of disease status with respect to its distribution and determining the economic importance of same and its likely impact on enset production. A database will be continuously updated with this information at Ambo Plant Protection Research Center, EIAR.

- Generation of information on etiology and epidemiology: The evaluation of inoculation methods for early screening of young plants, determination of pathogen variability, the methods of pathogen penetration into the host/alternate host, and modes and rates of transmission to other hosts; determination of survival
mechanisms and duration of the pathogen under different environments should receive due attention.

- **Development of appropriate technologies for disease management:** This could be done using farmers’ participatory approaches to evaluate and promote control measures known to be effective against other bacterial wilt diseases elsewhere, including removing male buds; rouging diseased plants; developing resistant/tolerant banana clones through conventional and genetic engineering methods and disseminating appropriate technologies for the containment and control of the disease.

- **Creation of awareness about the disease to reinforce control:** Strategies that focus on awareness creation through mobilization of farmers and their leaders to deploy sanitation based agronomic practices to protect unaffected areas, blocking further disease spread, eradicating the disease in the ‘frontline’ areas and coping with or eradicating the disease in already-affected areas should be strengthened. The awareness creation shall include preparation of illustrative posters, fliers, films in various local languages. The farmers training centers plays a vital role in awareness creation through short term trainings by developing appropriate modules.

- **Strengthening research and development capacities at all levels:** A strategy that addresses research and development with participation of scientists in training in specialized skills for handling BXW; training of trainers at district, sub-county and community levels; strengthening capacity of farmers’ grass-root institutions to handle BXW in pilot sites; and developing infrastructure for handling BXW.

- **Establishment of partnership among stakeholders at national and regional level:** Establishment of effective partnership with sound development plan to elucidate the vector-disease-host plant relationships in order to understand the survival strategies of the disease under a range of environments; develop appropriate technologies to curb long distance disease transmission and arrest intra-farm disease transmission. Conduct multi-location evaluation of germplasm linked to clean seed production systems at grass-roots platforms. Establishment of environment effects of the control measures on soil fauna and flora and soil conservation is very essential. Disease surveillance approaches linked to GIS and feeding into strategies for raising public awareness will strengthen the frameworks for mobilizing and empowering banana-chain actors to own the bacterial wilt problem and adopt approaches that will deliver quality bananas and enset production to the market.

- **Monitoring the impact of research and development:** To make appropriate adjustments to enset bacterial wilt strategies and accordingly to inform the government’s policy makers with respect to the management and control of the epidemic, it is important that the impact of research and development is continuously monitored. The implementation of the strategy need to be monitored and evaluated as deemed essential. However, it can be done twice a year and shall be reported to responsible body - the Agriculture and Rural Development Partners Linkage Council (ARDPLC).
Recommendation

At present focus shall be made to create wide awareness among the enset growers on the importance of sanitation based agronomic practices, the nature of the disease as any green enset plant can’t be assumed free from the disease unless it is tested and found free from same. Effective disposal methods of infected enset plants have to be communicated to farmers.

Disease free rhizomes can be propagated with the help of tissue culture to start with clean planting materials. The sanitation based agronomic practices need to be supported with early wilt detection techniques. This will make the sanitation practices more reliable when it is started with clean materials.

The awareness creation approach shall be more systematic using leaflets, posters and films. Modules and communication booklets have to be developed in local languages of the enset growers. Farmers training centers (FTCs) can serve as a good forum for awareness creation.

Regional collaboration is under way to develop PCR based diagnostic method in Kwanda Research Laboratory, Uganda in collaboration with IITA based in Tanzania. McKnight Foundation is planning to support the enset bacterial wilt project in Ethiopia at the same time rendering support to banana bacterial wilt project being undertaken by Bioversity International in Uganda and Kenya. Thus, the bacterial wilt project will have a regional program to strengthen the collaboration for managing enset/banana bacterial wilt in East Africa.

The Ethiopian Institute of Agricultural Research (EIAR) in collaboration with Regional Research Institutes shall be able to strengthen its ties with the regional bacterial wilt program. It should also play active role in the Banana Research network for Eastern and Southern Africa being coordinated by Bioversity International based in Uganda.
References


The Essence of Domestic Quarantine against *Enset* Bacterial Wilt during Technology Dissemination in Ethiopia

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Abstract

*Enset* (*Ensete ventricosum*) is widely cultivated in Ethiopia especially in the Southern part of the country and bacterial wilt is a serious disease. At present, enset is expanding to other areas through technology dissemination scheme by governmental and non-governmental organizations or individuals, which poses the risk of inadvertent introduction of this disease to new areas. For a country like Ethiopia with large differences in ecological and physical features, there is sound biological evidence that justifies domestic quarantine. An attempt was made to discuss on possibilities of effective domestic quarantine against *enset* bacterial wilt (EBW) during technology dissemination by considering the practical implications of the (i) behavior of the pathogen, (ii) ecology and distribution of enset, (iii) human activities, (iv) general quarantine principles, and (v) the development of agriculture to effect domestic quarantine. Establishment of *enset* nursery center (ENC) where clean planting materials are developed, inspected and certified by local government officials and extension services are proposed. In addition, how eradication programs at a country level could be launched with the participation of all concerned partners is mentioned. At a local level the possible development arrangement and important regulatory and mass mobilization issues that deal with ecological management of EBW is also discussed.

Keywords: Enset, diseases, bacteria, wilt, EBW, domestic quarantine, pest, risk analysis, Ethiopia

Introduction

About 25 species of *Ensete* are equally distributed in Asia and Africa (Mesfin and Gebremedhin, 2008). Among these species, *Ensete ventricosum* is widely grown in Ethiopia and is a staple food for over 20 million people in the Southern part of the country. It is estimated that about 146 thousand hectares in SNNPR and 79 thousand hectares in Oromiya are covered with enset (CSA, 2005). Presently, enset is expanding to other inherently non-enset growing areas of the country, especially to the north, through technology dissemination scheme by governmental and non-governmental organizations or individuals. This obviously poses the risk of
inadvertent introduction of serious diseases like enset bacterial wilt (EBW) and probably other pests to new areas of the country.

Therefore, quarantine precaution measures against inadvertent introduction of pests into new areas during dissemination and exchange of technologies were important topics at global level for many years. Likewise, in Ethiopia there was an extensive review of plant quarantine information regarding import and export certification of plant materials (Merid et al., 2008) while no mention was made on domestic quarantine. However, the plant quarantine guideline published by the Ethiopian Institute of Agricultural Research (EIAR) for National Agricultural Research System (Dereje, 2006) provides the possibility of effective precautions through production of disease-free planting materials with effective phytosanitary measures as components of domestic quarantine system. For a country like Ethiopia with large differences in ecological and physical features, there is sound justification to consider domestic quarantine when enset is introduced to new areas, particularly to the north part of the country, where there are big natural barriers.

Importation of plant materials into a new areas necessitates serious consideration of recent development in regulatory sciences based on sound biological, economical, social and policy issues. Thus, the current regulatory trend demands to consider guidelines and procedures outlined by the sanitary and phytosanitary standards (SPS) as per the international Plant Protection Convention rectified by the Government. This paper attempts to provide some possible measures and approaches of local regulatory measures in order to be effective during enset distribution within the country. This is because, introducing plant materials to new area requires to conduct pest risk analysis (PRA) that include initiation (based on specifics on import permits), risk assessment (determining the type and magnitude of the risk) and risk management (effecting phytosanitary measures to prevent the risk). Accordingly, this paper presents summary of EBW information and discusses the possibilities and procedures of domestic quarantine against enset bacterial wilt (EBW) during enset technology dissemination in the country. The discussion aimed to effect domestic quarantine action against EBW based on (i) behavior of the pathogen, (ii) ecology and distribution of enset and wilt, (iii) human activities relevant to enset production, (iv) mechanisms of quarantine, and (v) possible development arrangement to effect quarantine in enset growing regions. It considers EBW pathway analysis from major enset growing regions as a source of planting materials and new areas as importers of enset for planting. It also provides inspection and phytosanitary measures to safeguard the new enset areas. Finally, it forwards possible development arrangements and important regulatory and mass mobilization issues that deals with ecological management of EBW.
Enset bacterial wilt (EBW)

Wilt and the pathogen
Bacterial wilt of enset was first recognized by Dagnachew and Bradbury about four decade back (Yirgou and Bradbury, 1968). They identified the causal agent as Xanthomonas musacearum following sound biological evidences revealing a new Xanthomonas species at that time although the name was later changed to Xanthomonas campestris pv. musacearum (Jones et al., 2007). Very recently, however, comparative analyses of Xanthomonas campestris pv. musacearum with fatty acid methyl esters, genomic fingerprinting using rep-PCR and partial nucleotide sequencing of the gyrase-B gene showed some uniqueness in identity of this pathogen. Pathogenicity studies indicated that strains of X. vasicola pv. holcicola and X. vasicola from sugarcane induced no symptoms on banana, whereas X. campestris pv. musacearum produced severe disease (Aritua et al., 2007). This result supports a future reclassification of X. campestris pv. musacearum as X. vasicola pv. musacearum when more data are available. This pathogen, causative agent of enset wilt, is found in major enset growing regions of Ethiopia although it has not been yet reported on other Ensete species in other countries.

Although no information was found on enset, the incubation period of wilt was found to be at most 14 days on banana suggesting the possibility of fast detection of the disease during quarantine investigation (Ssekiwoko et al., 2006). Using hypersensitive reaction, no variation was detected in 90 isolates of the pathogen collected from enset grown in southern Ethiopian (Mesfin et al., 2008).

Host range
Enset and banana are natural hosts of Xanthomonas campestris pv. musacearum (Xcm) in Ethiopia (Yirgou and Bradbury, 1974). In Uganda Musa sebrina, M. ornate, and Canna indica were also found to be alternative hosts of this pathogen (Ssekiwoko et al., 2006). The pathogen was found to frequently devastate enset in Ethiopia and severely damage banana in Rwanda (Reerer et al., 2007) and Uganda (Ssekiwoko et al., 2006). DNA fingerprints were identical for Xcm isolates from enset in Ethiopia and Xcm isolates studied from banana in Uganda, Ethiopia and Democratic Republic Congo. Apart from these, no other hosts have been demonstrated to be similar so far. Nevertheless, it is possible that other closely related plant species in family Zingiberaceae, Marantaceae and Cannaceae could be infected by this pathogen although no evidence was found so far.

This pathogen causes typical wilt on banana like that on enset (Yirgou and Brandbury, 1974) and there was severe infection of banana in the country. In Ethiopia, 40 banana and 114 enset clones were tested for resistance using artificial inoculation by the pathogen. After 90 days, 98.5% incidence was recorded on banana
while only 68.8% incidence was recorded on enset with only 10% incidence in some clones (Mesfin et al., 2008). This indicates that Ethiopian banana industry is now at risk with this disease and the need for establishment of sound phytosanitary measures is highly indispensible.

**Transmission**
Transmission of *Xcm* from diseased to healthy plants occurs through many ways and contamination is the major mechanism. Contaminated farm tools and kitchen utensils (knives, machetes, spades, and hoes) are major inoculants (Dereje, 1985; Welde-Michael et al., 2008). Spread by animals browsing on infected leaves, use of infected planting materials, repeated transplanting which damage corms and roots, and possibly insects visiting bacterial ooze on enset foliage may also occur (Yirgou and Bradbury, 1974). Since enset is mostly harvested for its pseudostem and corm, it is not allowed to flower and thus insects infecting flowers in banana are not common in enset, and hence, this transmission mechanism does not seem to be important in enset in Ethiopia.

**Survival**
The bacterium causing wilt of enset does not seem to survive long under natural conditions. It survives only up to nine days in soil and up to 90 days in infected plant residues (Welde-Michael et al., 2007) when the inocula reproduced in artificial media was kept under different conditions to emulate natural situations. It did not survive for two months in soil when infected tissues were kept in 6cm depth. This indicates that the pathogen is short lived organism like many other bacteria which provides opportunity for effective phytosanitary measures.

**Basic Principles Relevant to Domestic Quarantine**

**Mechanism of Control Relevant to Enset Distribution**
Mechanism of plant quarantine operates under five set of guiding principles and procedures at domestic (local) or cross boundary (international) level. These are (i) embargoes, (ii) inspection and certification, (iii) disinfection, (iv) special permits, and (iv) unrestricted shipments. The scope of this paper is limited to only local precautions (domestic quarantine), embargoes and unrestricted shipments which are less relevant and hence the other three principles operate very well for enset under our conditions. In order to be effective, both pre- and post-entry quarantine measures for new areas are very important and complementary.

To be specific for enset technology dissemination within Ethiopian, possible pre-entry quarantine may include (i) importing enset from pest-free enset nursery centers (ENC), (ii) inspection and certification at the place of origin (ENC), (iii) production of disease-free seedlings with special arrangement, (iv) examination and thereby
sorting the planting materials (corms, suckers, seedlings, etc.) to salvage healthy seedlings. These measures are dependent on the results of pest risk analyses based on sound biological evidences. On the other hand, post-entry follow-up may include growing enset at closed fields, inspection and cleaning by rouging and disposing risky samples/plants. In Ethiopia the movement of planting materials is free and depends on the will of individuals. There is no policy related to internal quarantine by the regional governments. Hence, some of these principles are difficult to apply.

Accordingly, enset movement in Ethiopia requires a special consideration of establishing nursery fields at specific regions that serve as origin of clean planting materials and able to facilitate the inspection and certification procedures at local level. Healthy seedlings could be obtained by selecting, cleaning, sorting and destruction of diseased ones. In addition appropriate treatments could be possible to disinfect farm tools under local nursery arrangement. Individual farmers and/or cooperatives could be major actors upon receiving appropriate training and technical/regulatory backstopping by extension personnel. Under this arrangement, special permits could be given by local officials with advisory services by extension. These would enhance safe movement of enset in the country and enable the system to salvage safe planting materials, whenever possible, by restricting and destroying unsafe enset plants to avert the risk of EBW in the enset and banana industry of the country.

Pest Risk Analysis (PRA) Relevant to EBW
In actual practice, on a worldwide scale, issues of inadvertent importation of potentially hazardous pests into new areas arise in relation to several dimensions that include biological, economic, political and social scopes (Kahn, 1979). These are factors determining the entry status of enset planting materials, and subsequent follow-up in new areas. When only one of these factors, especially biological factor, is in use to determine the movement status of an item, the activity ought to be based on pest risk assessment (PRA). This is a thoughtful process whereby the movement status of enset plant, plant product, package, vehicle, used farm tools, common carrier, etc. is based on calculated risk of inadvertently introducing EBW with enset as moved by man (Kahn, 1979; Merid et al., 2008). Consideration of such arrangement could help to manage difficult diseases like EBW through selecting the most appropriate step to limit the spread.

PRA has three phases including (i) initiation, (ii) risk assessment, and (iii) risk management. Risk assessment considers two areas of information that eventually determine the pest balance of the areas. Pest balance, is the list of pests that are present in the area of origin minus the list of pests widely distributed in the importing region. From this, two pest categories including those potentially requiring phytosanitary measures and those pests excluded from the risk assessment are determined. Diseases of enset in Ethiopia are listed by Quimio and Mesfin (1996).
This information enables us to differentiate pests of quarantine concern to the region. Listing pests and determining the mode of transmission and dissemination from source to destination are important and useful tool to decide import permission or on the type and level of post-distribution follow-ups. The behavior of EBW raises concern as quarantine disease for new areas and all phytosanitary measures described in the previous section for enset movement within Ethiopia are also part of PRA.

Origin of EBW Risk and Possibility of Phytosanitary Measures

Behavior of the pathogen

*Xanthomonas campestris pv. musacearum* causes wilting of enset plant in short time and completely kills with no chance of recovery. Once enset got inoculated with the pathogen, no plant would remain from being infected or wilted. Contamination is the major mechanism by which the pathogen is transmitted from diseased to healthy plants and spread through regions. It is relatively a short-lived pathogen with narrow host-range. These types of pathogens are known to be venerable to sanitation practices and eradication campaigns. Thus, phytosanitary measures against EBW are important and feasible practices when implemented at country or regional level considering all hosts (*Ensete spp.*, *Musa sp.* and *Canna sp.*) that could harbor the pathogen.

EBW Incidence and Enset Ecology

The mean EBW incidence in the different agroecologies of the country Table 1 shows 0.94% in H2, 0.66% in SH2, 1.10% in SH1 and 0.42 in M2 agroecology in the country. EBW was not found in PH1 and SM1 zones. This clearly shows that EBW is a disease of mid to high altitude areas with humid and sub-humid climate. According to Mesfin et al. (2008), incidence was not influenced by agro-ecology and year. Evaluation of the data in Table 1 does not support this generalization. Thus further studies are necessary to verify about the ecology of the disease. Generally, there are many uncertainties in the identification of enset diseases due to lack of sound biological evidences. For instance, leaf streak virus and leaf narrowing, stunting and chlorotic leaf streaks might be the same disease but at different developmental stages. In addition, even if Addis et al. (2008) suggest that bacterial wilt spread from enset to banana grown alongside in Ethiopia and spread to banana in east and central Africa, no sound biological evidence was shown regarding its pathway. Therefore detailed studies are necessary to clarify the many doubts that hang around enset diseases in Ethiopia. Generally, enset regions are distributed in the Southern region of the country (Figure 1) and it is taken pushed to non-enset regions in the north. The wide ecological elasticity makes EBW management difficult without
strong development arrangement that ensures the use of clean planting materials and effects sound phytosanitary measures supported by community and extension services.

Regarding the host conditions, there were some signs of tolerance in clones of enset during screening trials for resistance and enset was found to be better tolerance than banana. Although information on the influence of varietal, age, soil fertility, moisture, temperature, season, etc. on EBW is lacking, it can easily be seen that enset pseudostems hold a lot of water in its tissue which is suitable for bacteria growth and multiplication. This situation may guarantee the pathogen to multiply and infect enset plant at wide ecology even if the weather becomes harsh. Any phytosanitary measures planned against EBW should include all natural hosts of the disease namely enset (*Ensete* spp.), banana (*Musa* spp.) and an ornamental plant (known as *Canna indica*) because these plants could serve as primary sources of inoculums.

### Table 1. Incidence of enset bacterial wilt during the 1998 and 1999 crop seasons in the southern region of Ethiopia

<table>
<thead>
<tr>
<th>AEZ Code</th>
<th>Description based on climate (altitude)</th>
<th>Sites studied</th>
<th>Incidence (%)</th>
<th>Area* (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>Tepid to cool humid (mid to high altitude)</td>
<td>Aletawendo, Bonga, Gazer, Gerese, Hagereselam, Jinka</td>
<td>0.94/4.20</td>
<td>1844</td>
</tr>
<tr>
<td>SH2</td>
<td>Tepid to cool sub-humid (low to high altitude)</td>
<td>Agena, Angacha, Gera, Jima, Leku, Limu</td>
<td>0.66/2.90</td>
<td>1688</td>
</tr>
<tr>
<td>SH1</td>
<td>Hot to warm sub-humid (low to mid altitude)</td>
<td>Areka, Dedo, Gunchere, Tocha, Waka</td>
<td>1.10/3.80</td>
<td>1684</td>
</tr>
<tr>
<td>M2</td>
<td>Tepid to cool moist (mid to high altitude)</td>
<td>Chelelektu, Feshagenet, Solemo, Yirgalem</td>
<td>0.42/1.30</td>
<td>712</td>
</tr>
<tr>
<td>PH2</td>
<td>Tepid per-humid (low to high altitude)</td>
<td>Shewa-Gimira</td>
<td>0.4</td>
<td>372</td>
</tr>
<tr>
<td>PH1</td>
<td>Hot to warm per-humid (low to mid altitude)</td>
<td>Mizan-tufere</td>
<td>0</td>
<td>204</td>
</tr>
<tr>
<td>SM1</td>
<td>Hot to warm sub-moist (lowland and plateau)</td>
<td>Gedeo</td>
<td>0</td>
<td>128</td>
</tr>
</tbody>
</table>

*Source:* Mesfin et al. (2008)
The Essence of Domestic Quarantine against Enset Bacterial Wilt

Human Activity

Seedling propagation
Enset is commonly propagated by vegetative means in all places and rarely from seed. During vegetative propagation, apical buds are removed from corms of two to six years-old enset by cutting the pseudostem, boring the apical meristem and scraping/removing old roots. Sometimes wilted shoot may be removed and the corms of these diseased plants are used as propagating material. These corms (healthy or diseased) are planted in a hole within enset field whether it is clean or infected soil. Fifty to 60, some times over 100, suckers emerge from this corm in two months. These manipulations involving cutting, boring, tiring and wounding somehow have direct or indirect influence in bringing the pathogen together with the host so that infection could take place, which affects the quality and health of enset seedlings.

Adult plant management
Owners of enset attend their field from establishment to harvest almost every day for transplanting, loosening the soil, placing cow-dung/trash from cleaning, cutting
leaves for animals, food preparation or marketing, and finally for processing and fermenting Kocho. Enset fields are not uniform and hence there could not be a break crop in all enset cultures. During enset development period a repetitive transplanting takes place particularly in Gurage areas. At the early stages, big seedlings are planted individually while weak ones are planted in group. These operations, like that of propagation, involve many wounding and smearing conditions where several tools and many enset plants are involved that may again increase the chance of bacterial wilt to initiate. Borrowing of tools and exchange of planting materials may increase the chance. In the same way, phytosanitary measures should consider these conditions and apply good agricultural practices that are eventually supported by code of conducts at local level and harmonized with “Kebele Rules”.

**Utilization of enset parts in kocho preparation and packing**

Pseudostems and corms of enset are chopped into small pieces and rolled by enset leaves and put into kocho and bulla fermenting pits. The fermenting dough is cut and mixed every 5-7 days for many times before getting ready for use. No evidence is available whether infected enset are mixed with or could still carry pathogenic bacteria after fermenting. If kocho dough carries the pathogen, all tools and utensil used to process uncooked Kocho and Bulla would also become important in spreading the disease. True stem (generative organ), bract, flower, fruits and seeds, might not be important in the epidemiology of EBW as they are not used much in the propagation of enset. Enset leaves are also used to pack many foods, dairy and vegetable products for market. Enset leaves as packing material could again become an important and critical source for the spread of EBW.

**Movement of enset**

Enset movement in the country (mainly to Amhara and Tigray regions, and probably to other drought prone areas) takes place for several purposes that include: technology transfer (local or selected clones by research), germplasm for research and for aesthetical values as ornamental plants. Fresh enset parts (particularly leaves) are used as packing materials while processed Kock and Bulla move as food materials for marketing. Any of these materials can come from diseased enset or even could be contaminated by tools and handling and carry the pathogen from its origin to their destinations and become sources of primary inoculums. Taking into account the current experience and that of banana wilt caused by the same pathogen in east Africa, once the pathogen enters an area it is difficult to eradicate. Therefore, limiting its distribution through strict local phytosanitary measures and strategic enset movement scheme becomes univocally essential and feasible when considering the experiences of domestic quarantine in other countries (PPS, 2008).
Possible Intervention Strategy

Enset movement and domestic quarantine
Strategic approaches are necessary to combat EBW. These include performing sound planning for movement of enset planting materials within the country, and to layout and provide appropriate working procedures and protocols for the local phytosanitary measures. This would be possible by implementing fully or partially the following tactical interventions for strategic approaches.

General Development Arrangement
- Define enset growing regions into distinct agro-ecology where the varieties (clones), climate, production and processing methods are distinct.
- Establish enset-nursery-center (ENC) that house all enset clones found in that specific agro-ecology to serve as a source of planting materials. Collect germplasm from similar agro-ecologies to enrich the ENC with local clones.
- Use only these nurseries as sources of planting materials for future enset distribution within the country.
- Develop good enset propagation and production practices (GEP) that is compatible to local practices and tools. Impose the GEP to locally endorsed code of conducts (Kebele Rules) for enset propagation, production and marketing. Use this Kebele Rules strictly as parts of local administration and extension services.

Inspection and Certification at Enset Nursery Center (ENC)
- Inspect the planting materials and propagating practices followed at ENC in order to provide healthy propagating materials to farmers.
- Certify enset seedlings from ENC by local extension and administrative services. A simple method to determine infection of enset by wilt pathogen is to uproot seedlings and cover them with white plastic sheet for two days to enhance bacterial growth in the plant. Then, cut the upper part of the seedling to observe bacterial presence. After half an hour, yellow bacterial ooze comes from conducting tissues which confirm infection. Infected plants are buried with all the cut tissues to keep the ENC clean.
- If the destination is Northern Ethiopia, examine at quarantine check posts of “Abay” and “Tarmaber”. Unless certified, the enset seedlings should not pass the check posts.

Eradication Programs of EBW
- EBW should be designated as a pest to be regulated by domestic quarantine that requires eradication programs at national level.
- Mobilize enset farmers and development partners for general campaign against EBW in enset region using simple decision and motivation tools (technical manuals, leaflets, posters, mass-media, etc).
- Major activities may include training farmers, inspection of fields, destroying and burying of diseased hosts (enset, banana and Canna ), and endorsing GEP for local uses. Phytosanitary measures described in the next section provides adequate operation protocol that need to be in the technical manuals used in the campaign.
• Maintain clean enset and banana farms by ensuring GEP with the help of extension services
• Monitor and evaluate results of eradication programs and document the success

Phytosanitary Measures Relevant to Local Conditions
• Use clean propagating and planting materials
• Remove, destroy, compost or deeply bury infected enset plants at soonest possible time. Enset like banana can be readily killed by 2,4D and Glyphosate herbicides (Okurut et al., 2006). Discourage movement of fresh enset materials in the field or between fields as it can effectively contaminate healthy enset plants or fields
• Disinfect farm tools (knives, machetes, spades, hoes, diggers, etc.) using flame or chemicals (Clorox = berekina) after being used
• Isolate enset fields by fence to control entrance of domestic and wild animals
• Avoid repetitive transplanting of enset, in other words rotating enset from hole to hole every season need to be avoided (this practice is common in Gurage zone)
• Distribute only very few (if possible only one) planting material. During corm movement, especial precautions should be followed on sanitation and disinfection
• Use rotation for at least one season or keep the hole open during the dry season as the life of the pathogen is short in soil
• Minimize exchange of farm tools with other farmers
• Enhance awareness and educate, especially women, on the transmission and control of the disease.

GAPS/ Challenges
• Lack of data for mapping the distribution of EBW that may facilitate the combat against the disease
• Lack of quantitative data on occurrence (seasonal appearance of wilt), prevalence (proportion of enset fields showing wilt) and incidence (proportion of wilted plants in a field) that understanding the impact of wilt based on actual and potential loss data is actually meager
• The relationships of wilt incidence to soil types and characters, altitude and temperature variation, drought incidence, rainfall patter bacteria essentially require abundant free water, age and variety of enset are lacking to formulate sound management strategy against EBW
• Scientific evidence on whether enset is really drought resistant/tolerant or not is lacking. The notion of enset as drought resistance/tolerant appears to be unlikely because all enset growing areas have enough rain (water) in the year and enset carries a lot of water in its tissue. Further in Abiro (a moisture stress area in south Gonder), only about 60 kg of enset was obtained in 6 years by sufficiently caring generating the doubt on the drought tolerance nature of enset (personal observation).
• Contamination as key factor in EBW development was not well understood by majority of enset growers, but the importance of the disease was well known. Thus, operation at community level and implicating subsequent phytosanitary measures at grass route level are challenges to the extension system as this demands strategic arrangement to avail clean planting materials at zonal level.
• There is a lack of awareness among enset growing community on the importance of contamination as primary factor of wilt in enset.
Acknowledgements

The author would like to thank Ato Dereje Nigussie (EIAR) for generating enset distribution map, Dr Eshetu Ahmed (EIAR) for discussions on EBW management and reference materials, and Mr. Endale Gudeta (HARC) for useful discussions on enset propagation and production in Southern Ethiopia.

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Mole Rat and Porcupine as Production Threat and their Management Options

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Abstract

Among vertebrate pests, porcupine and mole rat are the most important and damage a great deal of crops. Porcupine and mole rat eat mainly sweet potato, yam, enset, potato and cassava in Gununo watershed, Wolaita zone, SNNPRs. Africa Highlands Initiative (AHI) participatory problem identification and prioritization, farmers in the watershed put porcupine and mole rat as the most important vertebrate pests and brings tremendous crop losses. Collective action for the control of porcupine determine effective control methods, identify effective form of collective action institutions make use of local policies and social negotiation were the main objectives of the study. Participatory mole rat control zoas aimed at to identify the effective traditional mole rat control methods for further use in collective action. This paper explains that different steps were followed before mobilizing the collective action. Different tier discussions and negotiation was made from key-informant level to kebele level. The collective action utilize the traditional control methods such as deep ditch digging (3-4m deep), circular ditch digging around graveyard and wire trap were used. Zinc phosphide (RATOL™) as chemical control was used in combination with the first traditional control methods. In order to control the watershed-trial site, three additional adjacent Kebeles were added as a buffer zone, since porcupine travel 14.8 k over night, for mole rat control three Wolaita traditional mole rate control were compared with Ditta/chuncha trapping system. Developmental Group (DG) was identified as the most effective form of collective action institutions that able to enforce the by-laws for mobilizing the collective action against porcupine. The modified deep ditch digging with RATOL was the most effective control method in most porcupine niches except in graveyard, stony areas and underneath forest niches. Circular ditch digging with RATOL was effective in graveyard rather than using the traditional control method alone. Wire trap was found effective in stony and underneath forest niches. Frequent social negotiation and support were made between different interest group like least vs. most affected communities by porcupine, safety-Net vs. non-safety net farmers that helped a great deal for successful collective action at Gununo watershed. In participatory mole rate control, farmers selected Ditta/chuncha and Wolaita type-II as 1st and 2nd, respectively, and decided to use in the collective action at watershed level. The approach followed in the collective action against porcupine can be scaled out and replicated to other areas having similar problem. Institutionalizing the collective action will be decisive steps for sustainable vertebrate pest control when scaling out by any GOs and NGOs that will engage the same activities.
Introduction

Every year, crop and animal pests deprive farmers of significant parts of their production. Some estimates suggest that 10–40 percent of the world’s gross agricultural production is destroyed by agricultural pests. These pests include a huge variety of different organisms that include rodents, insects, mites, worms, birds, fungi, bacteria, viruses and virus-like organisms and weeds. Crested porcupine (*Hystrix cristata* L.) is a rodent, which causes a serious problem to farmers in many parts of East Africa including Ethiopia. The crested porcupine is the largest and heaviest of African rodents. It is one of the three species of East African porcupines. It is the most widespread one but followed by South African porcupine (*Hystrix afercaea*ustralis). The smaller, more slender African brush-tailed porcupine (*Atherurus africanus*) is found in isolated populations in Northwestern Kenya (Begashaw et al., 2007). In Southern Ethiopia including Gununo watershed, however, crested porcupine is the commonest resident. It belongs to phylum cordata, class mamalia, order rodentia and to the family Hystricide. It is easily recognized by its most notable feature—its quill, the stiff, thick spines banded with black, brown, pale yellow or white covering, side and tail, and they are mix in with soft hairs.

Porcupines inhabit holes made by other animals but also dig their own. They seem to prefer moving along tracks or roads, travel up to 14.5km at night in search of food. Three adjacent Peasant Associations (PAs) of Gununo watershed were considered to serve as a buffer zone for this study. Porcupines eat primarily maize cobs, followed by roots of sweet potato, leaves of cabbage, roots and tubers of yams, potato, cassava, and seeds of field pea. Graveyards, underneath trees and grassland are the most common types of habitat of porcupine in Gununo watershed though they prefer to live mostly in graveyards. This is because porcupines chew on bones for calcium and other minerals albeit they are vegetarians. Farmers' traditional knowledge assessment indicates that there are three different porcupine control measures. These are wire-body trap, fumigation of caves with farm straws and pepper mix; deep ditch digging (3-4m deep) at outlet of the porcupine cave, circular ditch digging around local graveyards, digging and destructing the tunnels to the cave, sound frightening material called “giraf”, Amharic during patrolling of porcupine at night.

These different traditional control methods are used in different niches of porcupine under different situations. In Gununo watershed, graveyard, grassland, underneath forest area and following riverside are the major porcupine niches identified in the study. Rodenticide like zinc-phosphide™ (RATOL™) is a registered chemical in Ethiopia to control rodents. It was used in combination with the fore mentioned traditional control measure pasted with maize cob or sweet potato roots.

In Gununo watershed, farmers have been claiming that mole rat (*Spalax spp.*) is also an important constraint to *enset*, maize, elephant grass, and cassava and coffee seedlings (AHI, survey on needs and problems assessments, unpublished, 2004).
Mole rats eat the roots of enset, sweet potato, wheat and barley, reducing the production of these crops significantly. They also eat grass and the soft part of any plant if there is no crop in the field. Mole rat enters a new field, start burrowing and throw up soil forming molehills. It continues forming tunnels while living there and traveling through them in search of food. According to the farmers, the living quarters of mole rats consist of four compartments linked by tunnels. These are: a sleeping area, a food storage area, a resting area, and a west accumulation area. The tunnels are zigzag, narrow and deep. Some farmers attempted to control mole rats through fumigating their holes, pouring water into the holes and using traps. There appeared to be a fair amount of indigenous knowledge and experience offering room for further research on the trap. It operates on the principle of a spring mechanism. It varies in the type of material used in making the noose or hooks. Some farmers use potato or ginger, to attract the rat toward the trap. Farmers at Gununo watershed, utilize a metal hook trap with different attractants and food baits.

Border of farms covered with grasses, and non-arable areas located between farms are described as potential habitable areas for mole rats. Informal assessment of farmers' coping strategies of these vertebrate pests showed that most farmers are lacking the techniques and alternatives for addressing the problem. However, some farmers who were equipped with skills and techniques used for working and manipulating of the trap. Digging and destroying the mole tunnels following the feeding runways were also investigated to be an alternative mole management option, particularly by those farmers who are not familiar with local trap.

Acquiring of trap shyness by the mole rates was raised and discussed among farmers as a drawback for using of the local trap. Some farmers worked out the reason and their experience with foreign odder induced from human being would be left on the trap, while working with the trap on the field. They speculated that such foreign odder could be the cause for orienting the mole rate to divert its route away from the direction where the trap is placed. Furthermore, farmers' indigenous innovation of rubbing hands with the soil obtained at mole mounds and applied during setting up of the trap was used to quite acquiring of trap shyness. Food baits prepared with sweet potato tuber or leaf, banana, or maize attached with aromatic plants ('Besobila' /' Koseret'), which induced attractive flavor for attracting the mole rate to the targeted trap.

In mole rate control, farmers' indigenous knowledge and innovations play significant role in the process of technology development and transfer. First, the best traditional control methods should be determined in selected experimental farmers in Gununo watershed. Hence, with the view to confirm and enhance their technical feasibility and efficiency to test and assess their performances in collective actions at community level for further use and utilization in mole rat management at watershed level.
Porcupines and mole rat do not respect farm boundaries. Therefore, farmers who control porcupine and mole rat niches on their own fields might still face damage on their crops caused by porcupine coming from neighbors fields or other villages where no control measure are taken. In that sense, crop damage caused by porcupine constitutes a trans-boundary natural resource management problem, which, in addition to technical interventions, requires organizational interventions to ensure a coordinated effort among farmers. Collective action for natural resource management that include joint investment for labor in pest management and introducing technologies; setting and implementing rules to exploit a resource is unequivocal for such pests. Trans-boundaries pest such as porcupine and mole rate needs an effective collective action. Collective action is often viewed rather uncritically as synonymous with social structures or formal organizations (Knox and Meinzen-Dick, 2000). There are many definitions for collective action processes that depend on its action or function in diverse biophysical socio-economic issues. In this study a collective action is defined as direct actions carried out by group of people working towards common goals (Lubell et al., 2002; Swallow et al., 2001; Tanner, 1995). This may range from two neighboring resource user managing a common boundary to a widespread social movement. Collective action tends to link property right and common resource governances. Hence, to conduct an effective collective action, there is a need to develop by-laws, by the community, which involved in the collective action, that govern the agreed upon action. Porcupine control at Gununo watershed should utilize collective action to make use of by-laws (local policies), effective forms of collective action institution (Developmental Group) and social negotiation among many interested groups.

Achievement

Methodology

Traditional knowledge assessment in the control of mole rat
In different localities, there exists diverse indigenous technical knowledge (ITK) for the control of mole rat. Farmers at Gununo watershed, use commonly a stick-spring with iron hooks, made by local artisans. The hook is tied with Eucalyptus sticks (that serve as a spring for the trap system) with enset fiber rope (Fig. 1). Different types of food bits (sweet potato roots, banana, etc) and attractants like “kosert” or “besobela” are used to trap mole rat. Other traditional mole rat controls methods used at the watershed include dig and destruct the tunnel following the tunnels or adding water into the hole. Based on FARM Africa’s experience on indigenous control methods in participatory experiment was carried out on two traditional trap methods viz., Gessa/Boreda and Ditta/Chencha. Their findings indicated that Ditta/Chencha were most preferred by the farmers and hence used in this experiment. Therefore, in this study, the following traditional control methods were utilized and demonstrated to farmers in Gununo watershed (Table 1). The experiment was carried out at four
villages’ watershed (Gegecho, Lay-busha, Tach-Busha and Offa) as a model and each one of them utilizing single traditional control method. A visit across the villages was made to share experiences and to decide on the most effective control methods for a collective action that is preferred by the farmers.

In each village where infestation was high and of similar level, a farmer field was selected to test the control measures. After a month, farmers visited the demonstration field and discussed with the farmers that conduct the experiment. The farmers evaluated the four traditional mole rat control methods based on the criteria set up by the farmers themselves. Farmers’ criteria were: time taken to set up the trap and its simplicity, availability of material for making the trap (cheap source and took less material), sensitivity (ability to trap instantly) and effectiveness (ability to kill/catch the rat). For each ITK, farmers’ evaluation was based on a 1-4 scale scoring methods (1 = bad, 2 = enough, 3 = good and 4 = excellent). The farmers in a group evaluated the methods and based on final consensus ranked the four mole rat control methods accordingly. Farmers were given 25 field pea seeds and distributed the seeds based on the different values/weights they gave for each criterion using PRA tools (Table 2).
Table 1. Description of traditional control methods used in the study

<table>
<thead>
<tr>
<th>Traditional control methods</th>
<th>Description of the methods/treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wolaita trap type-I</td>
<td>The trapping system consists of iron hook (that catch the mole rat), Eucalyptus stick (as spring), fiber rope (made of enset fiber), attractants (&quot;koserf&quot; or &quot;besobela&quot;), and food bite (sweet potato leaves/tubers or banana fruit).</td>
</tr>
<tr>
<td>Wolaita trap type-II</td>
<td>This trapping system is the same as Wolaita – I in terms of the iron hooks, attractants and food bait. The modification made on iron hooks are rubbed or pasted with soil from mole hill itself. This was based on some elite farmers’ experiences at the watershed. Farmers reported that strange orders from the iron hook and the person hand that set the trap cause the mole rat to escape in Type - I.</td>
</tr>
<tr>
<td>Dita/Chencha trap system</td>
<td>The trap is made of bamboo stick and string (&quot;Katcha&quot;) made from enset fiber. The string system has bamboo sticks (2-4 year old bamboo tree), loop and additional string system (made of one year old bamboo tree). The trap is set up on very recently made mole rat soil hill. The soil hill is removed, the tunnel outlet is closed with grasses material until the trapping set up is finished. The outlet then opened after finishing the set up so that mole rate sense the opening and bring soil by moving backwards towards the outlet. This is the time that mole rate will be trapped. The mole rate is trapped here without attractants and food bait like the Wolaita type. This system is based on the biology of the mole rat that it does not allow an opening along the tunnels and hence it is trapped while trying to fill the opening with soil.</td>
</tr>
<tr>
<td>Digging and destructing following mole rat tunnel</td>
<td>The digging follows the tunnels/pathways of the mole rat that lead to its resident area. Skilled person knows where to start the digging and the recent pathways that lead to mole rat area in the tunnel. This is labor intensive and is done only during wet and off season when there is no crop stand. Sometime digging takes much time and long distance, so it depends upon the knowledge of the farmers using this system. However, if it is dug by skilled person, then it is very effective.</td>
</tr>
</tbody>
</table>

Table 2. Farmers’ criterion value based on PRA tools

<table>
<thead>
<tr>
<th>Farmers criteria</th>
<th>Value/weight (n=25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time taken to set up the trap</td>
<td>8</td>
</tr>
<tr>
<td>Availability of materials and take less material to make the trap</td>
<td>4</td>
</tr>
<tr>
<td>Sensitivity – trap instantaneously</td>
<td>3</td>
</tr>
<tr>
<td>Effectiveness – ability to kill</td>
<td>10</td>
</tr>
</tbody>
</table>

After participatory evaluation of the different indigenous knowledge, one or two effective traditional control methods will be further utilized for collective action at watershed level.

**Porcupine Control**

The major steps to engaging on mobilizing the collective action are as follow:

**Local knowledge assessment**

First, the team discuss with Farmers Research Group (FRG) leaders to identify key informants who should be invited to elicit the views of men, women and diverse groups. Invite also influential people to set the agenda together with the informants for awareness creation. Then, this was followed by interviewing key knowledgeable informants about different control methods. Second, community consensus was reached on porcupine eradication. Hence, as per same agenda, further assessment of
Mole Rat and Porcupine as Production Threat and their Management Options

Identification of effective forms of collective action
The different local institutions such as local administration team (mengistawé buden), debo, edir, developmental group (DU), etc. assessed the effective forms of collective action. Then, consensus was reached at different tier of discussions with the farming community based on their ability to mobilize the collective action and enforce the formulated by-laws. The selected local institutions were also given responsibilities to engage in mobilizing the community and collect data using data collecting sheet (established reporting system) on number of porcupine killed/caught, methods of control, type of niches, etc using data collecting sheets.

Trainings
Capacity building on traditional porcupine wire-body-trapping system that was concealed before (since skilled farmers charges each farmers with 25 birr/a porcupine catch) will be given by skilled farmers to the community at four rural kebeles. The research team also will give orientation on the selected porcupine control method to be used and its suitability to a specific porcupine niche so that different types of porcupine control methods will be allocated for each type of niche.

Develop and endorse the by-laws.
The by-laws was formulated and endorsed by the community to govern the experiment so that all farmers participate and conduct periodic PM&E to monitor: a) implementation of agreed-upon action; b) the research process being implemented; c) the effectiveness of each treatment through a meeting with the community where research results are shared back.

Mobilizing the collective action and implementation of the research strategies/plan
Mega-phone and traditional horn instrument will be utilized for the announcement of the suitable type of porcupine control methods for each specific niche and the effective dates to start collective action for same. Mega-phone was used across all villages singing local songs that encourage and motivate farmers to endorse the collective action so that the selected effective porcupine control methods be effected.

Outcome Assessment
Farmers presented many traditional methods for the control of porcupine. Accordingly three methods were considered to be most effective: a) deeply dug pits at the outlet of a porcupine cave; b) circular ditches around graveyards, and c) a wire trap system. A forth chemical treatment, Zinc phosphide (RATOL™), was also used in combination with the first two methods as two additional treatments. Farmers
modified the first method of deep digging (3-4 m depth) to more shallow pit (1 to 1.5m deep) in combination with Zinc phosphide. Different porcupine control methods were selected based on their suitability to different niches within each Developmental Group’s site. Mobilizing the collective action for the aforementioned control methods were applied during the season when porcupines are most harmful to crops.

The research involved collective action across all sub-Kebeles under each Developmental Group (DG). Farmers selected DG units of collective action because they have the ability to enforce local by-laws in support of collective action and where only 25 to 30 households-may easily manage it and monitor activities during implementation. During the campaign, each DG assigned one to two days per week for collective action only to control porcupine in the watershed. It was further decided that the Rural Kebele magistrate court and local leaders to follow up the by-laws enforcement during the collective action.
Social negotiations were then supported among farmers whose crops are frequently affected and the least affected households, as well as those farmers who participated and not participated in the Safety Net Program1.

Then the by-laws were formulated through full participation of farmers and distributed to all Rural Kebele and Village/DG leaders.

The campaign was launched following the establishment of control method, administrative units and by-laws for the operation of the collective action and training the relevant individuals on the control methods and data collection procedures. Farmers travelled on foot and vehicles with mega-phones and local music thus publicizing the campaign across all DGs, villages and Rural Kebeles. Following the campaign, records were taken by DG leaders on the number of porcupine caught or killed by different farmers, villages, niches and the control methods.

The collective action for the control of porcupine was conducted at Gununo watershed as trial site and other three adjacent rural kebeles that served as buffer zones and the surrounding watersheds so that re-contamination from the nearby villages porcupine is protected (Fig. 2).

However, the impact/outcome study was conducted only for the Gununo watershed trial site. Since the collective action covered all villages of the watershed, amongst other methods viz., with and without, before and after, etc. Before and after impact assessment method was best suited and used for further impact assessment study. After mobilizing the collective action, then impact assessment was conducted using a structured questionnaire, which includes information such as number of porcupine niches and visited farmers’ plot, crop yield losses encountered per visit, frequency of porcupine visit per week, etc. To study the overall impacts at watershed level, focused-group discussion was made in four villages. Whereas household survey was used for least and most affected villages by porcupine. From least and most affected villages, Gegecho and Offa were selected, respectively for the former and latter villages based on their level of porcupine infestation. The data that were generated, were subjected for analysis using simple descriptive statistics.

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1 The Safety Net Program is a governmental program designed to help low income farmers by paying them to carry out, developmental activities (construction of schools, offices, health centers, road maintenances, and so on) for rural kebeles. Some non-participating farmers are uncooperative in the collective activities, arguing that Safety Net farmers must collaborate since they are paid to do so by the government. However, negotiations lead to the joint conclusion that porcupine are a problem for both parties and affect each group equally, requiring joint efforts by both groups.
Results

Mole rate control
The result of farmers' evaluations on on-farm experiment conducted with indigenous mole rat control methods at Gununo watershed showed that Ditta/Chencha trap was preferred than the rest with a total score X weight values of 84. It was also preferred because of its high sensitivity and high effectiveness in capturing the mole rat compared to the other three methods. Both Wolaita-II (Fig. 3) and Ditta/Chencha were equally valued (24) for simplicity to set up the trap. However, Ditta/Chuncha trapping system was valued the least by the discussant farmers in terms of available/cheap source of material to make the trap. In general, the evaluation conducted and the judgment made were subjective, the Chencha/Ditta trap was preferred because of its sensitivity and efficiency in capturing the mole rat (Table 3).
### Table 3. Farmers evaluation of different traditional mole rat control methods

<table>
<thead>
<tr>
<th>No</th>
<th>Farmers evaluation criteria</th>
<th>Wolaita-I</th>
<th>Wolaita-II</th>
<th>Ditta/Chuncha</th>
<th>Digging and destructing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Time to set up the trap/simplicity</td>
<td>2 x 8 = 16</td>
<td>3 x 8 = 24</td>
<td>3 x 8 = 24</td>
<td>1 x 8 = 8</td>
</tr>
<tr>
<td>2</td>
<td>Availability of material</td>
<td>3 x 4 = 12</td>
<td>3 x 4 = 12</td>
<td>2 x 4 = 8</td>
<td>3 x 4 = 12</td>
</tr>
<tr>
<td>3</td>
<td>Sensitivity</td>
<td>2 x 3 = 6</td>
<td>2 x 3 = 6</td>
<td>4 x 3 = 12</td>
<td>1 x 3 = 3</td>
</tr>
<tr>
<td>4</td>
<td>Effectiveness</td>
<td>2 x 10 = 20</td>
<td>3 x 10 = 30</td>
<td>4 x 10 = 40</td>
<td>1 x 10 = 10</td>
</tr>
<tr>
<td>Sum total value</td>
<td>54</td>
<td>72</td>
<td>84</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Rank</td>
<td>3rd</td>
<td>2nd</td>
<td>1st</td>
<td>4th</td>
<td></td>
</tr>
</tbody>
</table>

Depending on the choice of farmers, either the 1st or 2nd ranked traditional mole rat control methods can be used for collective action at watershed level or any type of administrative boundaries.

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**Porcupine control**

After mobilizing the collective action, then impact assessment was conducted using the before-after methods and structured questionnaire was prepared for focused-group discussion and household-household survey for each village and for least/most affected village, respectively. Collective action for the control of porcupine resulted in a significant impacts in reducing crops losses, reducing the time spent and labor required in guarding porcupine at night, improve the health of the community and change social attitude and behaviors. Gununo watershed, more than one thousand porcupines were controlled through collective action, social negotiations and by-laws implementation.
### Table 4. Number of porcupine killed/caught using different control methods in Gununo watershed

<table>
<thead>
<tr>
<th>Village</th>
<th>Niches</th>
<th>Control methods</th>
<th>No. of porcupine killed/caught</th>
<th>Total No. porcupine controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gegecho</td>
<td>Grassland</td>
<td>Wire trap</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Under Eucalyptus trees</td>
<td>Digging (1.5 m deep) at the outlet of porcupine hole + RATOL™</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grassland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lay Busha</td>
<td>Under Eucalyptus trees</td>
<td>Digging (1.5 m deep) at the outlet of porcupine hole + RATOL™</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>River basin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grassland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Digging (1.5m) deep at the outlet of porcupine hole + RATOL™</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tach Busha</td>
<td>Graveyard</td>
<td>RATOL™</td>
<td>18</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>Under Eucalyptus trees</td>
<td>Digging (1.5 m deep) at the outlet of porcupine hole + RATOL™</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grassland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Digging (1.5 m deep) at the outlet of porcupine hole + RATOL™</td>
<td>23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chere</td>
<td>Under Eucalyptus trees</td>
<td>Digging (1.5 m deep) at the outlet of porcupine hole + RATOL™</td>
<td>19</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Graveyard</td>
<td>Circular ditch digging + RATOL™</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grassland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Digging (91.5 m deep) at the outlet of porcupine hole + RATOL™</td>
<td>373</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offa</td>
<td>Graveyard</td>
<td>Circular ditch digging + RATOL™</td>
<td>107</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grassland</td>
<td>Deep digging at the outlet of porcupine hole</td>
<td>88</td>
<td>831</td>
</tr>
<tr>
<td></td>
<td>Under Eucalyptus trees</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Graveyards</td>
<td>Wire trap</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under Eucalyptus trees</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under forest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under bamboo tree</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Near river side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dembezamine</td>
<td>Graveyard</td>
<td>RATOL™ alone</td>
<td>173</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under Eucalyptus trees</td>
<td>Digging (1.5 m deep) at the outlet of porcupine hole + RATOL™</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Grassland</td>
<td>Deep digging at the outlet of porcupine hole</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Graveyard</td>
<td>Circular ditch digging + RATOL™</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grassland</td>
<td>RATOL™ alone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The three kebele-Buffer zones</td>
<td>Graveyard</td>
<td>RATOL™ alone</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Under Eucalyptus trees</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Under forest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grassland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Graveyard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grassland</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total number of porcupine controlled through campaign**: 984
Table 5. Methods applied by niche and their effectiveness

<table>
<thead>
<tr>
<th>Method of control</th>
<th>Niche where applied</th>
<th>No. of porcupine killed/trapped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method 1-RATOL™ alone</td>
<td>In graveyard</td>
<td>197</td>
</tr>
<tr>
<td>Method 2-Circular ditch + RATOL™</td>
<td>Porcupine burrow located near graveyards</td>
<td>126</td>
</tr>
<tr>
<td>Method 3-3.4m deep hole at the outlet of porcupine burrow</td>
<td>All porcupine burrow located away from graveyards</td>
<td>88</td>
</tr>
<tr>
<td>Method 4-1.5m hole at the outlet of porcupine burrow + RATOL™</td>
<td>All porcupine burrows located away from graveyard</td>
<td>455</td>
</tr>
<tr>
<td>Method 5-Wire-body trap</td>
<td>At outlet of porcupine burrow</td>
<td>92</td>
</tr>
</tbody>
</table>

Number of porcupine controlled at Gununo Watershed | 958

RATOL™ was tested as a means to reduce the labor associated with deep digging and to avoid digging in graveyard (Table 5). Different control methods were found to be effective for different reasons. Shallow holes dug at the outlet of the porcupine burrow combined with RATOL™ were most effective control method in terms of number of porcupine caught or killed (Table 5 and Fig. 4) and measured changes in local performance indicator. However, farmers are generally reluctant to use chemical control methods due to cost. In the absence of RATOL™, deep digging and wire traps may be used. The most livelihood impacts for farmers were due to reduced crop damage (80%), improved health and labor savings (Fig. 5). Levels of crop damages reduce by 80 % following intervention, and frequency of visits to health clinic from weather-related illness also declined. Yet, one of most important
successes in the mind of farmers was the reduction in effort required to guard the field at night.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Least affected village (Gegecho)</th>
<th>Most affected village (Offa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Harvested sweet potato (kg)</td>
<td>7.80</td>
<td>3.75</td>
</tr>
<tr>
<td>Yam (kg)</td>
<td>5.10</td>
<td>2.15</td>
</tr>
<tr>
<td>Harvested Potato (kg)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Haricot Bean (kg)</td>
<td>5.50</td>
<td>2.83</td>
</tr>
<tr>
<td>No. of porcupine niches</td>
<td>4.0</td>
<td>2.50</td>
</tr>
<tr>
<td>Frq. Of visit/week</td>
<td>4.2</td>
<td>1.30</td>
</tr>
<tr>
<td>No. guarding days/week</td>
<td>5.0</td>
<td>0.80</td>
</tr>
<tr>
<td>Time spent in guarding per night</td>
<td>3.7</td>
<td>1.05</td>
</tr>
</tbody>
</table>

In focused-group discussion, a total of 41 farmers whereas in household survey a total of 20 farmers in least most affected villages were interviewed using standard questionnaire. Crops like maize, sweet potato, yam, cabbage, tannia, haricot bean, cassava, field pea and pumpkin are the major liable ones to porcupine attack. Whereas taro, enset, wheat, barley and teff are rarely attacked by porcupine. Most (78.05 %) farmers responded that amongst major crops grown in the watershed, maize is the most preferred by the pest followed by sweet potato, yam and haricot bean.

The level of porcupine damage to crops was high (100% all farmers) in most affected-Offa village before the collective action was put into effect. However, after the campaign all the farmers' response were put within medium- and low-level ranges (Fig. 6). In least affected -Gegecho village, before the campaign, farmers' report was not high and after the campaign, most farmers (70%) report was within the low-level range (Fig. 6).

Illustration 1. Farmers witness on porcupine control

The high level of farmer enthusiasm for theses outcomes may be summarized by farmers' testimonies. While eating breakfast with one family, our host stated, "If there had been porcupine infestation in our village, we could have not shared this breakfast with you. The porcupine would have finished it." As stated by another farmer, "Observing our problem, God brought you to us."
Fig. 6. Percentage levels of crops attacked by porcupine before and after collective action in least affected (Gegecho) and most affected (Offa) villages.

Fig. 7. Percentage yield of sweet potato and yam achieve in most and least affected villages after, before collective action in the watershed.
As a result of mobilizing the collective action against porcupine, sweet potato yield was increased by 81.13% in Offa -most affected village. Whereas in the least affected-Gegecho village, yam yield increased by 57.84% (Fig. 7). As shown in Table 7, on average in the watershed, 75% of porcupine niches were controlled by collective action. The frequencies of porcupine visit to each farmer’s field per week, number of days spent for guarding porcupine by each farmer per week and time spent at night in guarding porcupine by each farmer were significantly reduced by more than 50, 80 and 70 percent, respectively. As a result of these most farmers were assured that labor demand in cold night and health condition were improved (Table 8). Farmers reported that, while guarding during cold nights they were exposed to different ailments such as pneumonia, TB and malaria fever. Farmers witnessed the overall impact as stated above in illustration 1.

Table 7. Porcupine niches before and after mobilizing collective action at Gununo watershed

<table>
<thead>
<tr>
<th>Watershed Village</th>
<th>No. niches controlled</th>
<th>No. niches not controlled</th>
<th>Coverage of collective action on porcupine niches (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lay Busha</td>
<td>5</td>
<td>0</td>
<td>100.00</td>
</tr>
<tr>
<td>Tach Busha</td>
<td>9</td>
<td>6</td>
<td>66.67</td>
</tr>
<tr>
<td>Offa</td>
<td>130</td>
<td>100</td>
<td>79.92</td>
</tr>
<tr>
<td>Chere</td>
<td>8</td>
<td>3</td>
<td>37.50</td>
</tr>
<tr>
<td>Mean</td>
<td>38</td>
<td>28.5</td>
<td>75.00</td>
</tr>
</tbody>
</table>

Table 8. Impact of collective action against porcupine on frequency of visit per week, number of days and time spent guarding, respectively per week and per night

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Least affected Village</th>
<th>Most affected</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Reduction</td>
</tr>
<tr>
<td>Frequency of visit/week</td>
<td>4.2</td>
<td>1.3</td>
<td>69.05</td>
</tr>
<tr>
<td>No. of days guarding/week</td>
<td>5.0</td>
<td>0.8</td>
<td>84.00</td>
</tr>
<tr>
<td>Time spent for guarding/night</td>
<td>3.7</td>
<td>1.1</td>
<td>77.62</td>
</tr>
</tbody>
</table>

Gaps

Farmers in many places try to control pest by themselves. Individual endeavors can only work for some pest that occur in certain locality and have not trans-boundary nature. However, pest that does not respect farm boundaries, in this case porcupines and mole rat require concerted efforts to work together in a form of collective action. Successful collective action that can enable mobilizing the farming community in a given watershed or administrative boundaries seeks effective participation of institutions, social negotiation and establishment of by-laws that govern the agreed upon action. Hence, for effective porcupine control, several steps were undertaken.
These include: social negotiation, awareness creation, training and different tire of discussions at key-informant level, village to kebele level to reach common understanding for subsequent community mobilization for the collective action. Before enforcing any forms of collective action. It is important to start with cheap and easily adoptable pest control measure in a participatory manner that is tested in the target community or watershed. In the control of mole rate, farmers at Gununo watershed, preferred Ditta/Chencha and Wolaita type-I which were ranked 1st and 2nd, respectively at the respective watershed. These effective control methods were demonstrated and tested at Gununo watershed indicating that aporcupine approach collective action can be utilized in a mole rat control collective action at watershed level. Thus, the approach used in porcupine control could be used for any type of vertebrate pest in any other localities where the pest pose threat for major crops grown in the area. Therefore, the approach need a scaling up effort particularly in enset based farming community, where mole rat and porcupine are among the major threat for enset production in the region. For sustainable control of vertebrate pests, it is important that collective action be institutionalized so that the existing GOs and NGOs together work actively in the region. Any development oriented institution should be unduly responsible to initiate and make institutionalized arrangement for mobilizing the collective action.

**Discussion**

Mole rat and porcupine bring tremendous crops damage and have been a threat to the production of crops particularly in root crops and enset based farming community. In the control of mole rat farmers preferred that Ditta/Chencha trapping system is best in terms of sensitivity and effectiveness. The finding of FARM Africa revealed that Ditta/Chencha trapping system preferred by farmers in the area because of its simplicity and takes short time to set up the trap than the Geresse/Boreda trap (FARM Africa, 2004). In general, the trail farmers and other farmers participating in cross visit demonstration, pointed out that Ditta/Chencha and Wolaita Type-II are more preferable to use for collective action at Gununo watershed. The Ditta/Chencha trapping system is so effective because it is based on the biology of mole rat. The trap is set in the open end of the tunnel. Mole rat does not allow the tunnel opened. It brings mass of soil moving backward to fill the opening. Then the mole rat gets trapped and eventually killed while trying to close the open end of the tunnel. Whereas, the Wolaita Type-II system, which is based on attractants and food baits, trap the rat while it is in search for food. Type-II was effective next to Ditta/Chuncca because it was modified by avoiding strange odder from the iron hooks and persons hand that set up the trap. However, most farmers in Gununo watershed, complain because using the ordinary Type-I trapping system,
mostly allows mole rat to escape or unable to catch it, since mole rat can easily identify the odder of the iron and the person who set up the trap.

The control of porcupine makes use of collective action that employs different traditional and chemical control depending on the different niches of porcupine. Based on assessment of traditional knowledge and literature reviewed, three most effective traditional control methods were selected. The modified deep ditch (1.5m depth with RATOL™ bait) was the most effective and reduced labor spent on digging up to 4 meter deep furrow. Most porcupines consume the RATOL™ bait set at the outlet of the cave because the shallow ditch discourage them to dig and forced them to eat the food bait pasted with chemical. In graveyard, circular ditch digging with RATOL™ was effective since porcupines are unable to dig deep ditch in a graveyard. Wire trap is used in a niche that is difficult to dig or stony area and underneath forest area. Hence, in the collective action for porcupine control wire trap was also one of the most effective in the aforementioned niches.

The effective control measure alone can control pests such as porcupine and mole rat unless it is embarked at larger area coverage like watershed or administrative boundaries that make use of collective action, social negotiation and local policies or otherwise. Pests like porcupine and mole rat do not respect farm boundaries that demand the community work together in a collective action (German et al., 2008). It is now widely recognized that collective action is a fundamental pillar of landscape or watershed natural resource management. Different from farm-level management, collective action require to regulate the rights and responsibilities of common property-resources and public goods (Gebremedhin et al., 2002; Munk Ravnbourg and Ashby 1996; Ostrom 1990; Scott et al., 2001), to manage biophysical processes that do not respect farm boundaries (Munk Ravnborg et al., 2000) to negotiate joint investments and technological innovations for enhanced productivity and to regulate benefit capture (Meinzen-Dick et al., 2002). Porcupine and mole rat control calls for individual farmers and resource users to come together to identify how agricultural productivity and livelihood more generally might benefited from collective action over individual action and to negotiate rules and regulations to govern such innovation.

In *enset* based farming system, these two vertebrate pests are threats for the production and productivities of the crop. At Gununo watershed, *enset* is less affected by porcupine because other root crops such as sweet potato, yam, taro, tannia, etc are available throughout the year. The approaches utilized to control porcupine in a collective action can be duplicable to other *enset* based farming area. Empowering institution to enforce the by-laws and institutionalize the collective action for sustainable porcupine and mole rat management the task remained need to be scaling up for other *enset* growing region.
Recommendation

A number of important outcomes and impacts can be achieved through collective approach to control porcupine and mal rat. It is of utmost importance that motivation for working together towards common problems/goals be increased among the watershed farmers. By doing so the time and energy spent in guarding the crops at night would be decreased considerably. Consequently, it will lead to substantial improvement in health quality and also increase household incomes and in food security from reduced crop losses by these pests. It is also essential to evaluate effectively farmers’ traditional control methods of the pests. Proper identification of control approaches and effective utilization of the methods for collective action at any region should receive due consideration.

The need for collective action in developing and maintaining resources and resource management technologies even at a micro-watershed level is of paramount importance. Robust collective management depends on the level of existing community organization and capital resource, which is the strength of the norms and social relations that enable people to work together to achieve their ultimate goals. Some technologies also need to be adopted over a wide area to be effective, so farmers who wish to adopt them must cooperate with their neighbors. It is essential that farmers jointly recognize the trans-boundary nature of pest management problems, in order to legitimize the otherwise socially unacceptable interference with the farming practices of others. The finding of this studies revealed that mobilizing the collective action for common NRM problem would significantly change the life of farmers in reducing yield losses and other social merits. Political leaders play a significant role in collective action for helping and enforcing the binding rules or norms that govern the agreed up on action. To make the collective action sustainable, it is advisable to involve different stakeholders with full commitments and must in place in their yearly routine work calendar.

References


Experiences on Enset Technology Dissemination and Value Chain Analysis

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Abstract

This paper highlights the status of enset technologies dissemination with respect to promotion of improved enset clones, enset processing devices, demonstration of improved enset decorticator and squeezer, extension advice to farmers concerning enset diseases, adoption of improved processing devices, case study in Southern and Oromia regions, enset marketing and value chain analysis, the case of Amaro special woreda. The gaps on enset technologies disseminations are identified. Enset production is highly affected by diseases, pests and vertebrates. Bacterial wilt, mole rat, porcupines and enset mealy bug are the major problems that influence the production system. The use of backward and inefficient traditional methods and equipment in production, processing and marketing activities, protecting and promoting the endogenous wealth of crops such as enset are major challenges. Most diseases are transmitted by farmers when they cut the affected and healthy enset plant with the same farm implements. Moreover, mixing of Bulla is cheap in the local markets as compared to prices in the other urban areas and central market but mixing it with foreign material would affect the exchange and contract enforcement in the product. The challenges and opportunities are discussed to draw appropriate recommendations in the area of interventions that are technically feasible, socially acceptable and economically viable. Scaling up cost effective and efficient enset processing devices for small scale and commercial farmers are mentioned. Promoting value addition for enset growing farm households from enset products such as bulla for starch extraction and fiber for industrial raw materials are recommended.

Introduction

The inadequate growth in production of food crops has led to increasing food insecurity in many parts of the country. The principal causes of insufficient growth in food production and for subsequent increase food insecurity are inadequate and unreliable rain fall as a major cause of drought, soil degradation, land tenure, geographical diversity, and population growth.

Enset has many different uses and contributes in securing food for smallholder farmers even at times of food shortage period and drought. Over 20 million people of
the Ethiopian population consume the crop as staple and co-staple food. The two major *enset* growing regions are SNNPR and Oromia. Farm households in *enset*-based agricultural system use the crop to feed their families and livestock. Other ethnic groups in the regions of Amhara and Tigray also use *enset* for feed and *enset* leaves used as wrapping material for butter, *bulla* and while baking bread.

The major food products of *enset* plant are *kocho*, *bulla* and *amicho*. *Kocho* is a bulk of fermented starch made from a mixture of the decorticated leaf-sheaths and grated corm. It can be stored for long periods of time without spoiling. The combination of *kocho* and *kitfo* is now virtually a common menu at restaurants. The best quality *enset* food, *bulla*, is obtained mainly from fully matured *enset* plants. It can be prepared as a pancake, porridge and dumpling. *Amicho* is the boiled *enset* corm, which consumed in a manner similar to that of other root and tuber crops. Certain clones are selected for their *amicho* production. Fiber is the non-edible product of *enset* left after decorticate leaf sheath at harvesting time. The fiber has an excellent structure, and its strength is equivalent to world fiber crop abaca (Godfrey, 1985). The fiber is also used to make bags, ropes, twines, cordage, mats and as wrapping material. Average yields of *kocho* range 31 to 60 t/ha/year, bulla 1.6-3.0 t/ha/year and fiber 201-400 kg/ha/year with great variability of clone types and its maturity period (Atanaua et al., 1980). The yield of *enset* exceeds other root and tuber crops. Hence, research, extension and development organizations should support *enset* production so that its role in the national productivity food security and poverty alleviation program would be strengthened. The major objectives of this review was to identify constraints and opportunities of production, processing and marketing, to assess the major value additive activities of *enset* along the value chain, and to evaluate the extent of *enset* processing devices dissemination.

**Methodology**

Secondary data are collected from published and unpublished sources such as the adoption of improved processing devises, case study in SNNPR and Oromia regions as well as marketing and value chain analysis the case of Amaro special *woreda*. Marketing margin and costs are discussed in relation to the services and functions provided. The Total gross marketing margin (TGMM) is the final price of the produce paid by the end consumer.

\[ TGMM = \frac{\text{Consumers' price} - \text{Farmers' price}}{\text{Consumers' prices}} \times 100 \]  

(1)

Producers’ share of the consumers price (PSCP) is the portion of the price paid by the consumer that belongs to the farmer (producer). The efficiency of any marketing system usually depends on the share of producers’ to the consumers’ price. The
better the efficiency of marketing, the better will be farmers' share of the of consumers' price.

\[
PSCP = \frac{\text{Price paid by the consumer} - \text{Marketing gross margin}}{\text{Price Paid by the Consumer}} \times 100 \quad \text{(2)}
\]

\[
NMM = \frac{\text{Gross margin} - \text{Marketing and transactions cost}}{\text{Price paid by the consumer}} \times 100 \quad \text{(3)}
\]

Where: 
- TGMM = Total Gross Marketing Margin
- PSCP = Producers' share of the consumers price
- NMM = Net marketing margin

**Achievements**

- **Enset Technologies Dissemination**
  
  The majority of extension, development, and research on Ethiopian agriculture have focused upon the cereal-based systems of the highlands of northern, central, and eastern Ethiopia, and to a lesser extent upon the shifting cultivation economies of sub-tropical and lowland western Ethiopia (Steven et al., 1997).

  The attention given for enset extension or technology popularization in the country as a whole was low as compared to other crops. Steven and his coworkers revealed that enset agriculture has received little attention on research, development and extension. The reasons may include: because: 1) the majority of enset farmers live in one of the least developed regions where making access and logistics are difficult; 2) the system is unique when compared to cereal farming; 3) production process is complex; and 4) there is the perception that it is eminently successful, sustainable, and trouble less crop.

- **Promotion of Enset Processing Devices**
  
  Ethiopian Institute Agricultural Research (EIAR) and Rural Technology Promotion Center (RTPC) have generated different enset processing devices (scraper and pressing device). These were developed and distributed in major enset growing areas of the country. To popularize the improved enset processing devices first contacts were made with communal institutions like farmers associations and service cooperatives. Through different institutions these devices or equipment were distributed to these communities free of charge for demonstration purposes. Deribe (1996) posit that in almost demonstrated areas farmers accepted the improved enset scraper and processing devices with few amendments for modification. From 1987 - 1992 a total of 180 scrapers and 32 processing devices were distributed in different enset growing regions in Southern Ethiopia.
Demonstration of Improved Enset Decorticator and Squeezer

Attempts have been also made by Hawassa Agricultural Research Centre to demonstrate and popularize the existing available enset processing technologies in major enset growing regions of Southern Ethiopia. The improved enset decorticator and squeezer were introduced in three major enset growing zones of Kambata Tembaro, Dauro and Sidama. Demonstration was carried out in selected PAs. The result indicated that in all three zones the decorticator and squeezer were accepted by the participated farmers. Farmers noted several advantages of the improved processing devices. These include: it produces quality cord; easy to operate; can be operated either standing or sitting positions; separates the “bulla” and “kocho” completely, thus produce quality bulla; saves labor and it is more hygienic. However, further improvements of the processing devices were suggested by the farmers as follows.

a. Improving the flat decorticator or clapper;
b. The squeezer is too narrow and heavy to move from place to place;
c. The opening and closing part of the squeezer should be flexible and lighter in weight,
d. The squeezer should be large enough to produce more bulla per unit time.

Improvement of Enset Processing Device

The traditional harvesting and post harvesting procedures are cumbersome; labor intensive, unhygienic, impose a lot of inconvenience to the working women, and associated with great yield loss. These methods of processing may reduce the quality and quantity of enset food and fiber. However, research has been conducted in several institutions to develop improved processing devices. The most prominent ones were the Institute of Agricultural Research at Melkassa and at Hawassa, the Ministry of Agriculture, and Hawassa College of Agriculture. Efforts have also been made to modify: 1) the decorticator that separates the leaf-sheath and pulp from the fiber; 2) the pulverizer that grates the corm into fine pieces; 3) the kneader that squeezes out unwanted water from fermented kocho; and 4) the shredder that chops the fiber from the fermented kocho. However, such devices are primarily experimental and have had little testing results and hence farmers’ acceptance did not materialize because of cost and inaccessibility (Metshen and Abate, 1994).

Adoption of improved processing devices

In order to improve the processing of enset products, some devices such as kocho scraper and bulla extractor were introduced and disseminated to farmers in Wolayita, Kembata-tembaro and Gurage zones between 1987 and 1992 (Deribe, 1996). Assessment made on the adoption, indicated that nearly half of the sample-farmers used the improved devices. Among the adopters, 88% suggested the need for further improvement (Table 1). Half of the non-adopters also indicated that the devices need further improvement to satisfy their needs under the circumstance. The other half of the non-adopters reported that the devices are convenient but could not adopt them due to financial problems (Million, 2008).
Table 1: Adopters’ and non-adopters’ reaction towards improved enset processing devices in Gurage Zone, 2001

<table>
<thead>
<tr>
<th>Devices' conditions/ Farmers reasons</th>
<th>Non-adopters</th>
<th>Adopters</th>
<th>X² statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
</tr>
<tr>
<td>The devices need further improvement</td>
<td>24</td>
<td>48</td>
<td>38</td>
</tr>
<tr>
<td>The devices are complex</td>
<td>34</td>
<td>68</td>
<td>39</td>
</tr>
<tr>
<td>The devices are expensive</td>
<td>13</td>
<td>28</td>
<td>34</td>
</tr>
<tr>
<td>Extension information</td>
<td>39</td>
<td>78</td>
<td>39</td>
</tr>
<tr>
<td>Availability of credit</td>
<td>8</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Improved devices preserve the usual taste</td>
<td>19</td>
<td>62</td>
<td>31</td>
</tr>
<tr>
<td>Thin hole in bulla extractor prevents easy passage of bulla</td>
<td>8</td>
<td>16</td>
<td>11</td>
</tr>
</tbody>
</table>

Note: ***=significant 0.01%, *=significant 0.05% and NS=None significant.
Source: Survey report, Million (2008)

Farmers’ decision to adopt or reject improved enset processing devices was influenced by the simultaneous interaction of technical, socio-economic, physical, and institutional factors. Out of 16 explanatory variables hypothesized to affect farmers’ adoption of improved enset processing devices, 9 were found to be statistically significant. The significant variables include: farm size, number of enset plants in a field, frequency of processing per year, extension information, farmers’ perception of the devices, taste of processed kocho or bulla, thin hole of bulla extractor, training and expensiveness of the devices.

- Enset marketing and value chain analysis

An agricultural value chain is usually defined by a particular finished product or closely related products. This includes all firms and their activities engaged in input supply, production, transport, processing and marketing (or distribution) of the product or products.

The value chain concept entails the addition of value as the product progresses from input suppliers to producers and to consumers. A value chain, therefore, incorporates productive transformation and value addition at each stage of the value chain where the product changes hands through chain actors, transaction costs are incurred, and generally some form of value is added. Value addition results from diverse activities including bulking, cleaning, grading, and packing, transporting, storing and processing (Fig. 1).

In agricultural value chain analysis, a stage of production can be referred to as any operating stage that is capable of producing a saleable product serving as an input to the next stage in the chain or for final consumption or use. Typical value chain linkage include input supply, production, assembly, transport, storage, processing, wholesaling, retailing, and utilization, with exportation included as a major stage for products destined for international markets. A stage of production in a value chain performs a function that makes significant contribution to the effective operation of the value chain and in the process adds value.
Coordination refers to the harmonization of the functions of a value chain—its conduct. The result of good coordination between the stages of a value chain may be reflected in a good match between buyer preferences and seller supplies. That is, better coordination in a value chain results in better matching of demand and supply between the chain stages, resulting in efficient and low-cost exchange, quality maintenance and value addition.

Agricultural value chain analysis can be viewed as a heuristic device or analytical tool (Kaplinisky and Morris, 2001). The research can be descriptive, perspective and designed to provide operational guidelines to improve efficiency of vertical coordination. Agricultural value chain analysis systematically maps chain actors and their functions in production, processing, transporting and distribution and sales of a product or products.

- Characteristics of bulla traders and marketing margin (Amaro special woreda, 2008);

Traders who appear in bulla transaction are rural retailers, assemblers, wholesalers and urban retailers. They rarely add value to bulla except place utility. They buy bulla from places of less demand to places where it is demanded more such as urban areas. Most traders complained that adulteration of bulla with kotcho and cassava with the motive to derive unfair profit is a threat to their endeavour and affected their bargaining power and contract enforcement.

Rural retailers buy bulla from farmers at farm gate or at the same market place for retail. They sell bulla to consumers or assemblers and use the premium for
purchasing the immediate and priority household needs. They are small in terms of resources and use personal or family labour for all activities.

Assemblers buy bulla from farmers or retailers mostly from Jijola and Kelle markets for resale to wholesalers in the neighbouring urban areas (Yirgacheffe, Dilla, Shashemene and Awassa). They regularly move between markets and face higher costs of transactions, accommodation and transport. They incur the cost of transport of goods, loading and unloading and absorb the risk inflicted by defects refused by wholesalers, urban retailers and consumers. They use motorized transport, ISUZU, in moving products from local to destination markets. Currently, about six assemblers are working as bulk buyers.

No strong boundary between wholesale and retail trader is observed. All wholesalers sell to consumers as retailers do. Many wholesalers have three to five hard core client retailers down stream and more than one supplier up stream. Wholesalers at urban area buy on credit from suppliers (assemblers) and sell on cash to retailers and consumers. Mostly they work in their own premises and sometimes it is rental. They are formal traders and pay between 400 and 500 Birr in renewing license annually. They frequently complain about the existing unfair level field between traders and the competition with unlicensed traders. The supply of bulla is declining both in quality and quantity. In such a situation it is increasingly difficult to stay competitive. Consequently, they have less incentive to stay in the business and prefer to switch to others up on study.

Gross marketing margins are highest at assemblers and wholesalers stage because of transactions and marketing costs arising from increased handling of products (Table 2). Assemblers and wholesalers also absorb costs of spoilage in the form of defects arising when dealing with poor quality bulla. Producers' share of consumers' price increases when sold locally by farmer traders and at distant markets by urban retailers. However, long distance sell to urban areas have a lot of transactions and marketing costs which is unbearable and expensive to small and scattered farmers. Further, trading in bulla has been risky and has a problem of contract enforcement. Given higher costs of handling and risks associated with marketing of bulla assemblers and wholesalers are receiving better return in the form of net marketing margin.
Table 2: Costs (Birr) and margins per average locally packed bulla (five kg) for different market operators

<table>
<thead>
<tr>
<th>Costs and margin</th>
<th>Rural retailers</th>
<th>Assemblers</th>
<th>Wholesalers</th>
<th>Urban retailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Marketing costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1. Purchase cost</td>
<td>24.00</td>
<td>25.00</td>
<td>31.00</td>
<td>34.00</td>
</tr>
<tr>
<td>1.2. Processing cost</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.3. Transport cost</td>
<td>-</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.4. Loading and unloading</td>
<td>-</td>
<td>0.12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.5. Tax and licensing fees</td>
<td>-</td>
<td>1.50</td>
<td>1.25</td>
<td>-</td>
</tr>
<tr>
<td>1.6. Tax</td>
<td>-</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1.7. Spoilage</td>
<td>0.10</td>
<td>0.20</td>
<td>0.20</td>
<td>0.10</td>
</tr>
<tr>
<td>1.8. Other costs</td>
<td>0.20</td>
<td>0.80</td>
<td>0.65</td>
<td>0.10</td>
</tr>
<tr>
<td>2. Transaction costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1. Opportunity cost of labor</td>
<td>0.25</td>
<td>0.30</td>
<td>0.55</td>
<td>0.40</td>
</tr>
<tr>
<td>2.2. Opportunity cost of capital</td>
<td>-</td>
<td>0.40</td>
<td>-</td>
<td>0.15</td>
</tr>
<tr>
<td>3. Total cost</td>
<td>24.55</td>
<td>30.32</td>
<td>33.65</td>
<td>34.75</td>
</tr>
<tr>
<td>4. Sales</td>
<td>25.00</td>
<td>31.0</td>
<td>35.00</td>
<td>35.00</td>
</tr>
<tr>
<td>5. Gross margins</td>
<td>0.45</td>
<td>0.68</td>
<td>1.35</td>
<td>0.25</td>
</tr>
<tr>
<td>6. Total gross margin</td>
<td>4%</td>
<td>19.35%</td>
<td>11.43%</td>
<td>2.86%</td>
</tr>
<tr>
<td>7. Producers share of consumers price</td>
<td>98.2%</td>
<td>97.81%</td>
<td>96.14%</td>
<td>99.29%</td>
</tr>
<tr>
<td>8. Net marketing margin</td>
<td>1.8%</td>
<td>2.19%</td>
<td>3.85%</td>
<td>0.71%</td>
</tr>
</tbody>
</table>

Source: Survey results, 2008 (Agri-Service, Amaro Special Woreda)

The value chain describes the full range of activities which are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use. Considered in its general form, it takes the shape as described in Figure 2. The environment, sequence of major events, detail activities and principal actors were identified along the value chain. As can be seen from this, production per se is only one of a number of value added links. Moreover, there are ranges of activities within each link of the chain. Although often depicted as a vertical chain, intra-chain linkages are most often of a two-way nature - for example, specialized design agencies not only influence the nature of the production process and marketing, but are in turn influenced by the constraints in these downstream links in the chain.

In addition to the manifold links in a value chain, typically intermediary producers in a particular value chain may feed into a number of different value chains. In some cases, these alternative value chains may absorb only a small share of their output; in other cases, there may be an equal spread of customers. But the share of sales at a particular point in time may not capture the full story - the dynamics of a particular market or technology.
Experiences on Enset Technology Dissemination and Value Chain Analysis

Fig. 2. Bulla value chain map
• **Marketing channels of bulla**

The survey data at Amaro, revealed that 41.3% of the marketable surplus of bulla passes directly from the producer or rural retailers to the consumers in the district. The remaining is taken outside of the district by assemblers and retailers (Fig. 3).

Generally, bulla reaches to the consumer in a variety of ways. These include: direct sales to rural and urban consumers; direct sales to farmer traders or retailers and assemblers at the market by farmers. More often, smallholder farmers transport bulla to the rural markets, mostly carrying themselves or by family members, and sometimes sell directly to farmer trader (retailers) at the farm gate or in the market, or directly to assemblers. In the major neighbouring urban centres, for example, in Yirga Cheffe and Dilla bulla originating from Amaro dominates the transaction. It appears that bulla from Amaro is of high quality than those products coming from other localities which are least demanded.

Bulla originating from rural areas of Amaro is transported as far as Hawassa, Shashemene and Addis Ababa. High quality and accordingly high unit value have improved its wider spatial transaction. High transaction cost in far-away market places is obvious as the product moves and changes through the chain. Costs in terms of transfer, attendants, risks (cost of physical deterioration and prices), loading and unloading, and opportunity cost of capital tied and labour is progressively increasing. This makes the product unaffordable to the majority of consumers. All through the chain most respondents disclosed that bulla coming from Amaro is quality but expensive. It is highly demanded by high income groups in the local as well as high income urban areas out side the district where many households are willing to pay.
**Gaps**

- *Enset* production is highly affected by diseases insect pests and vertebrates. Bacterial wilt disease, mole rat, porcupines and *enset* mealy bug are the major problems that influence the production system.
- The use of backward and inefficient traditional methods and equipment in production, processing and marketing activities,
- The existing extension service component doesn’t give enough emphasis on protecting and promoting the endogenous wealth of crops such as *enset*,
- Most diseases are transmitted by farmers when they cut the affected and healthy *enset* plant with the same farm implements,
- Mixing of *bulla* with foreign material is affecting the exchange and contract enforcement in the product,
- Bulla is cheap in the local markets as compared to prices in the other urban areas and central market,
- Enset products such as kocho, bulla and fiber were not adequately promoted for industrial inputs. Value addition for enset growing farmers could be possible if bulla extracted for starch and the fiber as raw material for various industrial products (sacks, different bags, mattes etc).

**Discussion**

The diagnostic survey (Million, 2008) was conducted in the Southern region (Masha district of Sheka Zone) and Oromiya region (Wenchi and Tikur Enchinii districts). The results depicted that the three most important factors responsible for the decline in enset acreage were bacterial wilt (47%), mole rate (13%) and moisture stress (16%). Various research experiments were attempted to screen enset clones against bacterial wilt under artificial inoculation. In addition the mechanism of pathogen dissemination and its survival was investigated. Hence, no chemical control measure was so far effective to control the disease. Therefore, several studies recommended sanitary control measures as a short-term solution to the disease (Dagnachew and Bradbury 1968; Dereje, 1985; Archido and Mwadin, 1993 and Million, 2008). Some of these include:

- Digging pit/hole 3 m deep and 2 m wide outside of the enset field
- Uprooting infected plant
- If the infected plant is big, chopping into small pieces without contaminating other plants
- Burying the uprooted plant in the prepared hole
- Finally disinfecting by flaming all farm tools used

The mature enset is usually allocated for process and household members participate in selecting the specific plant. Household head or male members of the family took part in removing all the leaves and uprooting from the plant. The subsequent tedious operation became the responsibility of women who perform either in group or individually based on the volume of work and urgency. A woman sits in front of a decorticating board made of wood inclined at certain degree and supported by strong mature standing enset plant. She lifts one leg and with it holds the leaf sheath to be decorticated on the wood. Bamboo splits that have sharp cutting edges on both sides are held by hand and the leaf sheath is scrapped step by step until white and strong fiber is remaining. The scraped leaf sheath piled together and the corn is chopped with special wood and mixed with the leaf sheath. The mixed part is called kotcho thereafter. In some places the wood has circular head on which there are smaller and pen like projections that are used for chopping and scrapping of the corn.

Bulla is the derivative that results during the processing of kotcho. The mass of kotcho then squeezed by applying enough pressure to release semi liquid substance. This is
allowed to stand for some time and after precipitation and dehydration it forms bulla. Despite the traditional bulla processing is an arduous task all the hand tools are locally made, cheap and easily available, but are out dated and mechanically inefficient.

Therefore, enhancing the adoption of improved enset processing devices among the enset growing households could bring about a significant impact for the farming community regarding the quantity and quality of enset bi-products.

Farmers have limited access to information regarding enset production technologies and marketing decisions. They predominantly produce these products traditionally for consumption and markets. Currently, new market opportunities are emerging based on the specific demand of consumers and/or end-use processors. These expanding niche markets, both domestic and international, provide opportunities for family-size farmers to exploit their comparative advantage in producing some types of value-enhanced products to specification.

To take advantage of these new opportunities, farmers may need to become more active participants in the value chain. First, they need to know what products are needed, including specific quality traits or attributes. Second, they need to know whether they have an inherent comparative advantage in producing these products in relation to other potential suppliers.

Development of grades and standards in bulla, training of farmers is of paramount importance. Providing genuine advice and other market operators not to adulterate the product, and also sanctioning those who exercise trade malpractice deserve serious measure. Furthermore, establishment of sustainable marketing groups or cooperatives and linking them with market in high income urban areas and central markets would unequivocal be beneficial.

**Recommendations**

This review paper highlights enset production constraints and less adoption of improved enset production technologies, the challenges and opportunities to enhance its production, productivity and marketing of the products.

Research institutions and universities in collaboration should support enset producers by developing/generating appropriate improved enset production technologies based on farmer's priority problems, to enhance enset production and productivity. The recent effort of other GOs and NGOs in promoting enset production technologies should be encouraged and strengthen to ease adoption of enset production technologies, which are compatible to enset-based farming system.

The relevancy of enset production technologies and the extent and rate of adoption should be assessed and accordingly establish sound strategy to enhance productivity
by providing sustainable training. Demonstration and scaling up of technologies
that have considerable impact to improve the livelihood of enset culture-based
farming communities in the country should be promoted.

The adoption of improved technologies for processing enset products by farmers is
hindered by socio-economic, technical and many other challenges and problems.
Therefore, efforts to facilitate adoption of the technologies should be strengthened.
For instance, it will be economically feasible to form small groups of farmers so that
they can collectively purchase or borrow the devices. The introduction of improved
enset processing should also consider the food habit of the society in a given area.

Assist in the development and dissemination of relevant and adequate market
information to small scale producers. This helps farmers to become more active
participants in the value chain. First, they need to know what products are needed,
including specific quality traits or attributes. Second, they need to know whether
they have an inherent comparative advantage in producing these products in
relation to other potential suppliers.

More emphasis should also be given to enset processing devices to alleviate the
tedious work and intensive labor requirement. It is also important to consider other
productive activities/options to the members to increase income of the household
and to improve the quantity and quality of kocho, bulla and other products of enset.
The promotion of the devices could be on credit and through partner organizations
participation in rural development GOs, NGOs and international organizations by
establishing kind of revolving fund raising mechanism.

Farmers indigenous knowledge and/or innovation on bacterial wilt control, mealy
bug and rodents should receive due attention along with the recommended sanitary
measures to alleviate the problems and improve production and productivity until
resistant/tolerant varieties are developed in the long term.

It is advisable to assess the marketing opportunity for enset products mainly for bulla
and fiber in Ethiopia. Diversifying enset production in potential areas and/or niches
to overcome the food insecurity at times of draught for household food and livestock
feeds is indisputable. Meanwhile, the supply of bulla for starch extraction and fiber as
raw material for small processing and larger industries could be achieved through
value addition so that farmers and industries could also produce at their capacity to
maximize profit. The raw materials supply from enset producing farmers should also
be complemented by organizing small groups in commercial farming of enset and
large scale plantation by the respective industries themselves.
Experiences on Enset Technology Dissemination and Value Chain Analysis

Reference


Research Experience and Achievements on Traditional Enset *(Ensete ventricosum)* Fermentation Processes

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Abstract

The paper reviews the available literatures on traditional enset processing techniques from enset maturity stage through processing to the final enset primary food products. Enset growers in different localities use different locally known maturity signs. These signs were not scientifically investigated whether they are appropriate maturity signs or not in relation to nutritional contents. Traditional enset processing for fermentation is tedious, unhygienic and generally done by women using locally made equipment. Attempts made hitherto on the modification of the process, in general, are not to the level needed as compared to the indigenousness of the process. Microbiological studies done so far on traditional enset fermentation process were concentrated on isolation and identification of the microbial population in the fermenting mass. Traditional enset fermentation was considered lactic acid fermentation. Here, attempts should be done to undertake controlled fermentation studies with selected culture starters and optimize the process into modern food processing technology. During post-fermentation time, it has been known that about 33% of the products were lost due to spoilage and lots of microbial contaminants were isolated from the products. Therefore, modification of storage facilities and scientific investigation of any related public health problems needs attention. Hence, understanding, improving and standardizing traditional enset fermentation process needs attention so that the burden on women can be minimized, quality and quantity of the food products get improved, the crop can wisely be used and contribute to the food security of the country.

**Keywords:** *Ensete ventricosum*, traditional fermentation
Introduction

Enset (Ensete ventricosum (Welw) Chessman) is a banana-like herbaceous and monocotyledonous plant. The plant is robust, ranging from 4 to 11 m in height and its pseudo-stem, which dilates at the base has a circumference of 1.5 to 3.0 m. Leaves are borne on the pseudostem almost from the same point and on short petioles, and are about 5 m long and 0.75 to 1.5 m wide (Taye, 1993).

Enset plant is particularly cultivated for its carbohydrate rich food products. The plant is used as staple or co-staple food for about 20 % of Ethiopian population particularly in the South and South-western part of the country (Brandt et al., 1997). According to Shigeta (1993), the utilization method of enset for food is classified into two groups: (1) the fermentation method of the pseudostem pulp and (2) the steam boiling method of the underground corm. Amicho, kocho, and bulla (names vary from one area to another) are the most commonly known primary food products identified and described from enset. Amicho is made from enset corm and is immediately consumed after it is boiled (similar to other root and tuber crops) without being fermented. Kocho is obtained from the pseudo-stem and corm after fermentation. Bulla (pure starch) is a purified product of kocho and is highly valued. It is the precipitate that formed when kocho is drained through a fine mesh (Liyulvork, 1993; Shigeta, 1993; Sandford and Helen, 1993). Annual production of these primary food products is estimated to be remarkable. In 1994 the production in Southern Nations, Nationalities and Peoples Regional State (SNNPRS) alone (Shank and Chernet, 1996) were estimated to be about 4,653,075 and 355,439 metric tons of kocho and bulla, respectively. These primary food products have been produced for generations by an age-old traditional enset processing techniques. Hence, the objective of this paper was to review studies made by various researchers on the traditional enset processing techniques with special attention on traditional enset fermentation processes. These processes are discussed.

Enset maturity and fermentation process

Enset plant, particularly for fermentation in earthen pit is normally harvested at full maturity (3 to 9 years) when it is thought to have high storage of food in the pseudostem and corm. Farmers use different indicators of maturity. According to farmers in West Shewa Zone, when enset matures, the inflorescence becomes shorten and the junction of the pseudostem and corm becomes clearly visible above the ground (Dereje and Endale, 2003). Farmers in Masha Woreda use drying of outer leaf sheaths and inflorescence as an indicator of enset maturity (Million et al., 2003). Other reports indicated that starch content of the plant is influenced by age of harvesting. Enset harvested too young and too old has reduced starch content (Kelbessa et al., 1993; Liyuwork, 1993). It is very imperative to scientifically identify appropriate maturity indicators which coincide with time of high nutrient content.
Identification of matured enset plant is a very crucial step to begin harvesting and processing. Identification of mature enset plant, harvesting and processing is generally the responsibility of women and the job is usually done in group (Belay et al., 2008). Though, basic traditional enset processing steps are the same, some steps differ from one locality to another (Seifu, 1993). During enset processing for fermentation, various multiple steps are incorporated, though pseudostem decortications and corm pulverization are the most common steps in all enset culture areas of the country. During processing, most of the works are done side by side by sharing responsibility amongst the women in the group. The generalized traditional enset processing for fermentation among the Wolayita and Sidama people and in Western Shewa Zone was described by Mehtzun and Yewelsew (1994) and Tariku and Mogessie (2011), respectively (Figs. 1 & 2).

After selection of mature enset plant and harvesting, pseudostem decortications and corm pulverization continues using traditional equipment to yield mass of enset which is going to be fermented in an earthen pit. In this process bulla is extracted from fresh decorticated pseudostem mass. Bulla extraction method also varies from one locality to another. Most of the time, the decorticated mass is put into a perforated sack and squeezed allowing the extract to run down into a pit lined with a plastic sheet. The filtrate is allowed to stand for some time to allow the thick paste to settle leaving the watery supernatant above the sediment. The watery supernatant is discarded and the white settled thick paste that remain is thinly spread over a clean leaf sheathes or sheet of clothes to dehydrate (Mogessie, 2006). The dehydrated, white powder is called bulla. There is a controversy on whether bulla is fermented or unfermented primary food product. In some localities, bulla is considered as unfermented primary food product (Tariku, 2008) and is also reported as fermented product in other localities (Kelbessa et al. 1997).

The decorticated mass and the pulverized corm are mixed thoroughly and put into a pit dug inside the enset plantation. The pits’ inner side is lined with fresh enset leaves. The mass is tightly covered and layers of more fresh leaves are put on the surface. Finally, fermentation is allowed to proceed after putting heavy logs and stones as weight over the tightly wrapped and sealed mass, possibly, to ensure the creation of airtight anaerobic conditions in the pit (Mogessie, 2006).

**Initiating the fermentation process**

Some enset growing localities use starter to initiate the fermentation process. Sandford and Helen (1993), reported the use of a mixture of herbs, orange, banana, onion and garlic, which are rubbed into the sides of the corm as starter in Morocho Wallano. Another study indicated the use of herbs and a small amount of fermented kocho (left from the previous fermented kocho) as a starter (Liyuwork, 1993). According to Kelbessa et al. (1993), small separately fermented corm (corm rubbed with a black mass just picked up from rotten enset leaves, shigido) is used as a starter. Study in West Shewa Zone also indicated the use of a starter called gamma.
processed corm and rubbed with herbs, Koricha gamma is used as a starter culture after it is changed to liquid form (Tariku and Mogessie, 2011; Dereje and Endale, 2003). According to these authors, gamma is used to speed up enset fermentation as bikil (malt), which is used in beer preparation. There is general believe that the pulverized mass will not ferment by itself unless mixed with the starter (Kelbessa et al., 1993). However, it is known by some authors (Brandt et al., 1997) that some enset growers process enset without addition of any starter. When no starter is used, the pulverized mass was laid on the ground in ambient temperature for about two to three days to begin the fermentation process (Brandt et al., 1997). In some localities, the mixed mass is covered with enset leaves and left at ambient temperature for two to five day to initiate fermentation (Berhanu, 1987). In the mid altitude of Western Shewa, the mass is wrapped tightly with enset leaves and left at ambient temperature for about two weeks to initiate the fermentation process (Tariku and Mogessie, 2011). The role of these homemade starters and their microbial population has not been investigated to date.

To ferment the pulverized mass, it is kept in the pit from a few weeks to several months or years of incubation period depending on the ambient temperatures (Mogessie, 2006). Different authors have reported different length of incubation time for different localities (Sandford and Helen, 1993; Liyuwork, 1993; Kelbessa et al., 1993). Study done on two different altitudinal ranges showed that the warmer temperature of the fermenting mass at the mid altitude site contributed to the rapid proliferation of microorganisms and hence rapid fermentation process and shorter fermentation time than at the high altitude site (Tariku and Mogessiei, 2011). Berhanu (1987) also reported that the fermentation process terminated within three to six months of time in wormer regions. Though, time length of fermentation varies from one enset zone to another, there is a general consensus that the longer the fermentation time in the pit, the more tasty the food products are. According to Kelbessa et al. (1993), enset cultivators use the long time fermented enset primary food products as a prestige food for guests and ceremonial occasions.

During this fermentation time length, various processing steps such as reopening, remixing and changing leaves lining the pit is done at varying interval of time for different localities. For instance, study by Sandford and Helen (1993), in Morocho Wallano (Northwest Wolayita) explained that the fermenting mass is moved to freshly lined pits every fifteen days. Study in Western Shewa highland and mid altitude showed that remixing, checking-up and changing of leaves lining of the pit is done only when undesirable odor was detected and at every 15 day interval, respectively, until the fermentation process is considered completed (Tariku and Mogessiei, 2011). At the completion of the fermentation process, a moist fibrous mass called kocho is obtained.
1. DECOUPTICATION  2. PULVERIZATION  3. MIXING  4. FERMENTATION
5. SQUEEZING  6. KNEADING  7. SHREDDED  8. SIFTING

Fig. 1. Steps of enset processing for fermentation in Wolayita and Sidama (source: Mehtuz and Yewelsew, 199...
Research Experience and Achievements on Traditional Enset Fermentation

Mature enset plant

Preparing the plant for
decortications, smashing
and pulverization

Decortications, smashing
and pulverization

Processed enset mass

Put into a pit

Wrap tightly and leave at
ambient temperature to ferment
(about 2 weeks)

Add 'jamma,
mix &

Remixing,
checking up &
changing leaves
(at some
time interval)

Wrap tightly
with enset

Fermentation proceeds
about a month)

Wrap tightly
with enset leaves

Fermentation proceeds

Kolcho
(Fermented primary food
product)

Bulla
(Extracted primary
food product)

Amicho (corm
consumed
after boiling)

Fiber
(by

Fig. 2 Flow chart of traditional enset fermentation process at high and mid altitude sites of
Western Shewa Zone (Source: Tariku and Mogessie 2011)
Microbiology of traditional enset fermentation

Microbiological studies on traditional enset fermentation process particularly at its natural pit are relatively inadequate as compared to other traditional fermented foods of Ethiopia. Berhanu (1987) studied and described the microbiology of traditional enset fermentation and also indicated the similarity of the microorganisms to those involved in the fermentation of other vegetables (Table 1). It has been believed that enset fermentation is a microbial disintegration of the grated corm and pseudostem and imparts flavour and textural qualities to the fermenting primary food product (Kelbessa et al., 1997). A microbiological study conducted on traditional enset fermentation process in its actual pit (Berhanu, 1987) reported Leuconostoc spp and Lactobacillus spp as groups of lactic acid bacteria (LAB) that bring the desirable changes in the fermented primary food product. Meaza and Berhanu (1985) identified Lactobacillus, Pediococcus, Leuconostoc and Streptococcus from kocho and bulla purchased from different markets in Addis Ababa and suspected these microorganisms to be involved in the fermentation process. Another similar study (Ayele and Berhanu, 1993) also isolated these microorganisms from fermented kocho purchased from markets in Addis Ababa. Kelbessa et al. (1997) revealed that traditional enset fermentation is primarily lactic acid fermentation. Steinkraus (2002) classified traditional enset fermentation as lactic acid fermentation. Tariku (2008) isolated Lactobacillus, Streptococcus and Leuconostoc spp from traditionally fermenting enset mass over the fermentation time. Berhanu (1987) reported Leuconostoc mesenteroides as an initiator of traditional enset fermentation process. But, in another study (Tariku and Mogessie, 2011), this bacterium was not detected in a considerable amount; rather coliforms and amylolytic Bacillus spp were found to be dominant at the beginning of traditional enset fermentation process. The Bacillus spp. was anticipated to contribute to the breakdown of starch to simple sugars favoring the proliferation of LAB that can utilize simple fermentable sugars. The coliforms were also anticipated to produce acids (lowering the pH) and created favorable condition for the LAB (Tariku and Mogessie, 2011). These differences might have been resulted as reports were from different fermentation conditions, the fermentation process may vary from place to place depending on various factors. According to Tariku and Mogessie (2011), after initiation of the fermentation process, the fermentative microbial population was gradually dominated by homofermentative Lactobacilli, resulting decrease and increase of the pH and titratable acidity (TA) of the fermenting mass, respectively (Table 2). The lowest pH reported during traditional enset fermentation was about 4.30 and 4.20 (Tables 1 & 2).

The heterolactics are more important than the homolactics in producing flavor and aroma components such as acetaldehyde and diacetyl (Jay, 2000) and were not usually detected during active fermentation stage of traditional enset fermentation process. The usually sour-tasting product of kocho could also be due to the activity of predominant homofermentative Lactobacilli, which produced more acid than the heterolactics. During traditional enset fermentation process, yeasts were also isolated from fermenting enset mass over the fermentation period. Tariku and Mogessie
isolated yeasts to the level of $6.62 \times 10^4$ cfu g$^{-1}$ at the highland and $1.12 \times 10^5$ cfu g$^{-1}$ at the mid altitude and reported that their fermentative activities were less likely due to their low number. The low number of yeasts could be due to some factors that can prohibit yeast proliferation, which requires an abundant continuous supply of oxygen. This is not the case during traditional enset fermentation process. Berhanu (1987) also isolated, identified and reported four yeast genera; *Trichosporon*, *Torulopsis*, *Rhodotorulla* and *Candida* from traditionally fermenting enset mass. In this report, it was also not sure whether these yeasts were participating in the fermentation process or simply as spoilage organisms. However, some report revealed the fermentative activities of yeast along LAB (Kelbessa et al., 1997; Amoa-Awua et al., 1997; Amoa-Awua et al., 1996; Oyewole, 1992). Such discrepancies could also be because the reports were from different fermentation conditions and indicate that the process may vary from locality to locality.

Aerobic and anaerobic spore forming bacteria were also isolated from traditionally fermenting enset mass, market *kocho* and *hulla* (Meaza and Berhanu, 1985; Berhanu, 1987). The spore former were dominated by *Clostridium* spp. *Kocho* is known to have a characteristic butyrous smell (Kelbessa et al., 1997; Berhanu, 1987) and this was suggested to be as a result of activities of clostridial species (Berhanu, 1987).

**Effect of fermentation on nutritional content**

Kelbessa et al. (1997), conducted a study on biochemical changes of traditionally fermenting enset mass (Tables 3, 4 & 5). They showed a reduction of total protein, ash and total carbohydrate by 15 %, 16 %, and 34 %, respectively. In the same manner, a progressive decline in carbohydrate content was observed and this was assumed to occur due to activity of microbes, which derive their energy from metabolism of carbohydrate. The level of soluble and reducing sugars increased during the first three weeks of fermentation and was assumed to happen as a result of activity of native microbial amylases. At the end of the fermentation period, sugars decreased significantly which is also assumed to occur as a result of metabolism of these sugars.
Table 1: Estimated number of organisms/g dry weight of fermented kocho

<table>
<thead>
<tr>
<th>Fermentation (days)</th>
<th>pH</th>
<th>Moisture (%)</th>
<th>Temp. of Kocho (°C)</th>
<th>Spore Formers</th>
<th>Leuconostoc spp</th>
<th>Streptococcus faecalis</th>
<th>Pediococcus cerasiæae</th>
<th>Lactobacillus spp</th>
<th>Yeast</th>
<th>Total count*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.5</td>
<td>84</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1 x 10^1</td>
</tr>
<tr>
<td>2</td>
<td>6.3</td>
<td>75</td>
<td>17</td>
<td>-</td>
<td>3 x 10^1</td>
<td>7 x 10^1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1 x 10^1</td>
</tr>
<tr>
<td>4</td>
<td>6.0</td>
<td>72</td>
<td>16</td>
<td>-</td>
<td>1 x 10^4</td>
<td>2 x 10^2</td>
<td>-</td>
<td>1.5 x 10^2</td>
<td>6 x 10^1</td>
<td>1.04 x 10^4</td>
</tr>
<tr>
<td>6</td>
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<td>15</td>
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<td>4 x 10^8</td>
<td>4 x 10^3</td>
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<td>4.01 x 10^6</td>
</tr>
<tr>
<td>8</td>
<td>5.6</td>
<td>66</td>
<td>15</td>
<td>2 x 10^3</td>
<td>3 x 10^7</td>
<td>9 x 10^2</td>
<td>1 x 10^1</td>
<td>3.3 x 10^5</td>
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<td>3.33 x 10^7</td>
</tr>
<tr>
<td>10</td>
<td>4.9</td>
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<td>17</td>
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<td>3.6 x 10^9</td>
<td>9 x 10^2</td>
<td>4 x 10^3</td>
<td>5.4 x 10^3</td>
<td>9 x 10^9</td>
<td>9 x 10^9</td>
</tr>
<tr>
<td>12</td>
<td>4.5</td>
<td>60</td>
<td>18</td>
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<td>1.3 x 10^7</td>
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<td>1.67 x 10^10</td>
<td>2 x 10^3</td>
<td>1.67 x 10^10</td>
</tr>
<tr>
<td>29</td>
<td>4.4</td>
<td>60</td>
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<td>8 x 10^2</td>
<td>4 x 10^5</td>
<td>-</td>
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<td>2.1 x 10^9</td>
<td>3 x 10^3</td>
<td>2.1 x 10^9</td>
</tr>
<tr>
<td>36</td>
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<td>59</td>
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<td>2 x 10^6</td>
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<td>-</td>
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<td>7.6 x 10^7</td>
</tr>
<tr>
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<td>5 x 10^4</td>
<td>-</td>
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<td>1.1 x 10^7</td>
<td>9 x 10^3</td>
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</tr>
<tr>
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<td>4.2</td>
<td>60</td>
<td>16</td>
<td>8 x 10^1</td>
<td>1 x 10^3</td>
<td>-</td>
<td>-</td>
<td>6 x 10^2</td>
<td>8 x 10^1</td>
<td>6 x 10^2</td>
</tr>
<tr>
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<td>60</td>
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<td>1 x 10^2</td>
<td>6 x 10^4</td>
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<td>60</td>
<td>18</td>
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<td>1 x 10^2</td>
<td>-</td>
<td>-</td>
<td>1.25 x 10^4</td>
<td>1 x 10^1</td>
<td>1.27 x 10^4</td>
</tr>
</tbody>
</table>

*Population less than 10/g dry weight of fermenting kocho
**Values represent the sum of Lact. coryneformis sub sp. coryneformis and Lact. plantarum populations.
# Count represents the sum of the microorganisms present at any one of the fermentation periods.
(Source: Berhanu, 1987)
### Table 2. Changes in means pH, TA, temperature and moisture during traditional enset fermentation at two different altitudes

<table>
<thead>
<tr>
<th>Fermentation time (day)</th>
<th>pH</th>
<th>TA (%)</th>
<th>Temperature (°C)</th>
<th>Moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mid-alt.</td>
<td>Highland</td>
<td>Mid-alt.</td>
<td>Highland</td>
</tr>
<tr>
<td>0</td>
<td>6.05a</td>
<td>6.11a</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>5</td>
<td>5.87b</td>
<td>5.89b</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>15</td>
<td>4.72c</td>
<td>4.89c</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>36</td>
<td>4.63d</td>
<td>4.86c</td>
<td>0.07d</td>
<td>0.07f</td>
</tr>
<tr>
<td>52</td>
<td>4.52e</td>
<td>4.77d</td>
<td>0.18bc</td>
<td>0.13e</td>
</tr>
<tr>
<td>66</td>
<td>4.38f</td>
<td>4.62e</td>
<td>0.18c</td>
<td>0.14cd</td>
</tr>
<tr>
<td>82</td>
<td>4.36f</td>
<td>4.31f</td>
<td>0.18c</td>
<td>0.15c</td>
</tr>
<tr>
<td>97</td>
<td>4.34q</td>
<td>4.30f</td>
<td>0.20b</td>
<td>0.20b</td>
</tr>
<tr>
<td>112</td>
<td>4.31h</td>
<td>4.32f</td>
<td>0.23a</td>
<td>0.22b</td>
</tr>
<tr>
<td>127</td>
<td>Final</td>
<td>4.33f</td>
<td>Final</td>
<td>0.30a</td>
</tr>
<tr>
<td>142</td>
<td>4.33f</td>
<td>0.30a</td>
<td>0.30a</td>
<td>0.30a</td>
</tr>
</tbody>
</table>

Mid-alt= Mid-altitude = 2252 masl  Highland=2908 masl  ND= not determined  Values are means of three determinations  Means in a column with the same letter are not significantly different from each other at 5% level of significance (DMRT).  

Source: Tariku, 2008
to glycolytic end products such as lactic acid and other volatile organic acids.

The amount/level of iron, phosphorous and calcium also decreased significantly. Perhaps, this could be attributed to the possible leaching out of the nutrients through the permeable fermentation pit. In the contrary, the amount of free amino acids and non-protein nitrogen (NPN) were found increasing and this is assumed to occur as a result of proteolytic fermentation of enset. However, the study on enzymatic activities of bacterial isolates from traditionally fermenting enset mass showed more dominantly amylolytic than proteolytic and lipolytic (Tariku and Mogessi, 2011). Such nutritional content loss deserves attention for modification of the traditional fermentation pit. The existing general consensus that disclosed the longer fermentation period improves taste of the enset food products also deserves further clarification in contrast to this declining situation of most of the nutritional contents.

**Keeping quality and post-fermentation loss**

Traditionally fermenting enset mass in an earthen pit and enset primary food products during storage has showed spoilage problems. Fermenting enset mass in an earthen pit especially for an extended period of time has shown spoilage problem; and the disease manifest itself by bad smell and it can easily be transmitted from infected to uninfected enset products. The spoilage is suspected to be caused by fungal species (Brandt et al., 1997). Fungi such as *Penicillium* sp., *Aspergillus* sp., *Cladosporium* sp., *Scopulariopsis* sp., *Rhizopus* sp. and *Mucor* were isolated from enset primary food products bought from market and were suspected to be contaminant (Meaza and Berhanu, 1985).
Table 3: Effect of fermentation on proximate composition of kocho (dry wt basis)

<table>
<thead>
<tr>
<th>Period (week)</th>
<th>Moisture (%)</th>
<th>Total protein (%)</th>
<th>Fat (%)</th>
<th>Crude fiber (%)</th>
<th>Ash (%)</th>
<th>NPN (%)</th>
<th>Free amino acids (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>84±3</td>
<td>4.07±0.02</td>
<td>0.43±0.01</td>
<td>3.43±0.03</td>
<td>0.75±0.01</td>
<td>0.01±0.01</td>
<td>8.1±1.2</td>
</tr>
<tr>
<td>1</td>
<td>66±4</td>
<td>3.97±0.01</td>
<td>0.43±0.00</td>
<td>4.07±0.02</td>
<td>0.76±0.03</td>
<td>0.01±0.00</td>
<td>9.0±1.0</td>
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<tr>
<td>2</td>
<td>63±2</td>
<td>3.87±0.03</td>
<td>0.42±0.00</td>
<td>4.13±0.03</td>
<td>0.78±0.04</td>
<td>0.03±0.00</td>
<td>10.7±0.8</td>
</tr>
<tr>
<td>3</td>
<td>60±5</td>
<td>3.75±0.01</td>
<td>0.41±0.01</td>
<td>4.21±0.05</td>
<td>0.75±0.03</td>
<td>0.05±0.02</td>
<td>12.4±0.9</td>
</tr>
<tr>
<td>4</td>
<td>60±3</td>
<td>3.63±0.00</td>
<td>0.53±0.04</td>
<td>4.33±0.02</td>
<td>0.67±0.00</td>
<td>0.06±0.01</td>
<td>16.9±1.0</td>
</tr>
<tr>
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<td>60±7</td>
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<td>0.43±0.05</td>
<td>4.37±0.03</td>
<td>0.65±0.02</td>
<td>0.06±0.00</td>
<td>18.8±1.2</td>
</tr>
<tr>
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<td>3.47±0.03</td>
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<td>4.50±0.05</td>
<td>0.64±0.01</td>
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<td>20.0±0.8</td>
</tr>
<tr>
<td>7</td>
<td>60±4</td>
<td>3.47±0.01</td>
<td>0.43±0.05</td>
<td>5.00±0.04</td>
<td>0.63±0.04</td>
<td>0.07±0.01</td>
<td>20.7±0.7</td>
</tr>
</tbody>
</table>

Values are means ± S.D. of three determinations

Another study associated appearance of molds, with poor wrapping of fermenting mass, increased acidity and decreased moisture content (Tariku, 2008). Study conducted in the laboratory on primary food products bought from market isolated aerobic mesophilic flora dominated by Micrococcus and Bacillus spp. (Mogessie and Yewelsew, 1996). This study also suspected psychrophilic bacteria and molds as an important cause of spoilage during cold storage. Some Gram-negative rods and non-lactic Gram-positive cocci were occasionally picked from the aerobic mesophilic counts due to occasional contamination and unhygienic processing environment (Tariku, 2008).

Table 4: Effect of fermentation on carbohydrate components of kocho (dry weight)

<table>
<thead>
<tr>
<th>Period (week)</th>
<th>Starch (%)</th>
<th>Total sugar (%)</th>
<th>Reducing sugar (%)</th>
<th>Non-reducing sugar (%)</th>
<th>Available carbohydrate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>68.8±2.5</td>
<td>4.3±0.1</td>
<td>1.9±0.3</td>
<td>2.4±0.4</td>
<td>72.1±0.4</td>
</tr>
<tr>
<td>1</td>
<td>68.5±1.4</td>
<td>4.0±0.4</td>
<td>1.5±0.1</td>
<td>2.5±0.3</td>
<td>72.1±0.5</td>
</tr>
<tr>
<td>2</td>
<td>65.9±3.7</td>
<td>3.5±0.3</td>
<td>1.2±0.2</td>
<td>2.3±0.0</td>
<td>72.0±0.7</td>
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<td>3</td>
<td>57.0±3.1</td>
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<td>4</td>
<td>55.3±0.7</td>
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<td>0.8±0.0</td>
<td>3.7±0.4</td>
<td>57.8±0.8</td>
</tr>
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</tr>
<tr>
<td>6</td>
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<td>0.3±0.1</td>
<td>0.8±0.2</td>
<td>54.0±0.9</td>
</tr>
<tr>
<td>7</td>
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<td>–</td>
<td>54.0±0.7</td>
</tr>
</tbody>
</table>

Values are means ± S.D. of three determinations
Table 5: Effect of fermentation on minerals and antinutritional factors of kocho (dry weight basis)

<table>
<thead>
<tr>
<th>Period (week)</th>
<th>Ca (mg/100g)</th>
<th>Iron (mg/100g)</th>
<th>P (mg/100g)</th>
<th>Tannin (mg/100g)</th>
<th>TIA (TIU/g)</th>
<th>Oxalic acid (mg/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>288.0±23</td>
<td>3.4±0.1</td>
<td>154.3±11</td>
<td>676±41</td>
<td>8356±11</td>
<td>230±32</td>
</tr>
<tr>
<td>1</td>
<td>283.7±23</td>
<td>2.8±0.3</td>
<td>149.0±10</td>
<td>644±34</td>
<td>8137±120</td>
<td>228±23</td>
</tr>
<tr>
<td>2</td>
<td>271.7±17</td>
<td>2.5±0.4</td>
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<td>440±23</td>
<td>7954±177</td>
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</tr>
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<td>3</td>
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<td>430±31</td>
<td>6520±123</td>
<td>224±22</td>
</tr>
<tr>
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<td>186.3±21</td>
<td>2.4±0.0</td>
<td>131.7±11</td>
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<td>5184±130</td>
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</tr>
<tr>
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<td>2.2±0.3</td>
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<td>128.0±21</td>
<td>333±21</td>
<td>3924±110</td>
<td>220±34</td>
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</tbody>
</table>

Values are means ± S.D. of three determinations. (Source of Tables 3, 4 & 5: Kelbessa et al., 1997)

About 33% of the products were known to be lost due to spoilage during storage (Mogessie and Yewelsew, 1996). Enset cultivators store enset primary food products for some extended time by using traditional techniques that are believed to improve the keeping quality of the products. Wrapping the products with enset leaves and burying them (most frequently used), changing wrapping leaves weekly and changing pits consequently aerating, and changing leaves used for lining pits every month were the methods used (Mogessie and Yewelsew, 1996; Brandt et al., 1997). About 57% and 70% of enset cultivators around Hawassa managed to keep bulla and kocho respectively, two to three months without spoilage by using such traditional techniques (Mogessie and Yewelsew, 1996). In the Gamo highlands fermented enset primary food products were stored for five to six years (Olmstead, 1974). According to farmers in Wolaita, fermented enset primary food products can stay up to eight years (Alemu & Sandfortd, 1991). It is also reported that kocho can be stored for up to 10 years or more by adding and thoroughly mixing fresh kocho (Liyuwork, 1993). It has been suspected that the long stay of the products could be due to LAB dominantly found in the products and reduced pH of the products that is inhibitory for most microbes that do not tolerate acid (Meaza and Berhanu, 1985; Berhanu, 1987; Ayele and Berhanu, 1993). The occurrence of enterobacteriaceae to the level of \(6.95 \times 10^6\) cfu g\(^{-1}\) at early stage of the fermentation process and total inhibition of them towards the final stage of the process. The inhibition was assumed to be resulted possibly due to the antimicrobial substances produced by lactic acid bacteria (Tariku and Mogessie, 2011). However, roles of LAB in the preservation of enset primary food products and as to why those traditional methods improve the keeping quality of the products need further investigation.

Loss of enset primary food products at this stage, after long years of investment on the plant through cultivation and processing is extremely serious. In addition to loss of the products, such spoilage problem may cause health risks, as most molds can produce heat resistant mycotoxins. Works done on post-fermentation loss of enset primary food products are very minimal and no scientific attempts have been made to improve storage facilities for the products. Though all enset foods are well heat
treated, some related public health problems such as existence of mycotoxins really needs scientific analysis.

**Research Gaps and Recommendations**

*Enset* plant has been traditionally fermented for generations in an earthen pit into carbohydrate rich primary food products. This age-old traditional method has been used for generations without any scientific modification. Studies done so far on traditional *enset* fermentation and its primary food products mainly focused on evaluation of effect of length of fermentation on carbohydrate and calcium content (Taye, 1984), isolation of microorganisms from fermenting mass (Berhanu, 1987), isolation of microorganisms from *enset* primary food products from market (Meazaa and Berhanu, 1985; Mogessie and Yewelsew, 1996) and biochemical changes during fermentation (Kelbessa *et al.*, 1997).

Okafor (1992) reviewed the extent to which some important fermented foods of sub-Saharan Africa had progressed toward commercialization. He measured the stage that each food had attained on a scale of eight. Very few Ethiopian fermented foods included in his review were categorized at a stage of scale one and two, which means that the works done focused mostly on isolation and determination of role(s) of microorganisms involved in the food, respectively.

The recommended research priorities on traditional fermented foods include; (1) improving and understanding of the fermentation processes; (2) refining of the processes; (3) increasing the utilization of the processes; and (4) developing local capabilities (Anon, 1992). Therefore, improving the understanding of traditional *enset* fermentation process is very crucial to scientifically promote the process forward. According to Yong (1992), without the knowledge of the art of traditional food fermentation, scientist cannot provide scientific explanation for the process and proceed to provide further assistance in improvement of the process.

Though, traditional *enset* fermentation has been practiced for generations here in Ethiopia, there are lots of challenging issues yet to be considered. Farmers in different regions use different maturity signs. However, identification of appropriate maturity indicators which coincide with time of high nutrient content is important. Traditional *enset* processing for fermentation is tedious, unhygienic and generally done by women using locally made equipment. Modification of the processing equipment can minimize energy and time consumption and can also improve sanitary conditions during processing for fermentation. Attempts should be done to undertake controlled fermentation studies with selected culture starters and optimize the process into modern food processing technology. *Enset* is a multipurpose crop and it is everything for the farmers (Brandt *et al.*, 1997). According to the authors of, "Lost Crops of Africa", no plant on earth can match *enset* for the
number of products it provides (National Academy Press, 2006) and hence can certainly contribute to food security of the country.

**References**


Research Experiences on the Development of *Enset* Processing Equipment

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Abstract

The processing of *enset*, both the root and the pseudo-stem has been a back breaking exercise imparting physiological stress on the operators, who are usually women. To overcome these problems, concerted efforts have been made by individuals and few organizations including the Ethiopian Institute of Agricultural Research (EIAR) and Debub University. The Agricultural Mechanization Research Division of EIAR at Melkassa made major improvements on the clamping component of the pseudo stem decorticator and amicho pulverizer. Different generations of devices were developed in the process. The first generation was tested at Weliso and Endeber, the second generation at Chencha, and Areka. Based on the feedback gathered from the above places, the required modifications were made and tested at Tikur Enchine and Buea. The clamping device on the pseudo-stem decorticator, avoided the stretching of the leg above the waist position for holding in place the pseudo-stem. The newly improved amicho pulverizer has dramatically cut down the time of pulverizing to less than an hour for the whole corm compared to three hours taken in squatting position in the traditional way. Four manufacturers from the Kofele and Butajira were trained for one week in a workshop organized by the Melkassa Agricultural Mechanization Research Center at Melkassa. Periodic improvements are being made on the device. The device operated smoothly on smaller diameter and softer varieties, while harder varieties were better operated by splitting the whole into two halves as observed at Tikur Enchine. The weight of the corm pulverizer is still higher than the required level and there is no provision for mobility to move it from one village to the other. The research is required to work hard and overcome these challenges. Despite these, the improved devices will lessen the drudgery on the rural women, who are responsible for the processing of *enset*. It will also help to create manufacturing jobs and or private mobile *enset* processing operators in the rural areas similar to tractor hiring and combine service providers.

Introduction

*Enset* is a banana like plant, which is a major source of food for a substantial number of the population. It has three major parts: the leaves, pseudo-stem and corm. The decorticated pseudo-stem and the pulverized corm are buried to ferment in a pit
lined with the leaves for few days. It is the source of food and fiber, where the fermented product from *enset* is processed into various types of food and its fiber is used in the manufacturing of ropes. It is widely grown in the highlands of South-Central and Southern Ethiopia supporting more than ten million people. The Gurage zone is one of the important administrative zones where *enset* is widely grown. The two main *enset* products utilized as food are locally known as *kocho* and *bullu*. *Kocho* is the fermented product obtained from the corm and pseudo stem of *enset*. *Bulla* is made by dehydrating the juice collected during the decorticating of the pseudo-stem and grating of the corm. It is readily available and is a very suitable crop for human consumption. It can be made into a number of traditional products either in the form of moist or dried product by using simple technology.

**Traditional Method of Processing**

The harvesting of *enset* in most parts of the country begins at the end of October and continues till January. For processing the whole plant is uprooted with the help of a special knife and brought to the processing site - an open place within the plantation (Fig 1). A wooden plank is put at an angle of about 40° against a pole. A woman sits in front of the plank keeping a pseudo-stem piece with its concave side against the plank securing it in position by putting her foot on it as high as possible (Fig. 2) (Kelbesa Urga et al., 1996).

The corm after removing the rootlets is grated (Fig. 3) and thoroughly mixed. The mass is called *amicho*. Graters are traditionally made from animal shoulder bones or pieces of wood. *Amicho* is squeezed by trampling before being placed in the fermenting pit. It is believed that *amicho* will not ferment by itself unless mixed with separately fermented *enset*, *kocho*. As a starter the *amicho* is rubbed with *shigido* - a black mass picked from the rotten *enset* leaves. The *shigido* wrapped *amicho* is left for five to seven days until it becomes soft and pulpy. This softened *amicho* is grated into finer mesh and mixed thoroughly with the fresh *amicho*, pressed down by trampling. It is covered with *enset* leaves and is left to ferment. The *enset* product is considered ready for consumption after 90 days from the initial processing day, but can also be kept for one or more year (Kelbesa Urga et al., 1996). Generally the processing of *enset* is a back braking exercise, which is a burden on the rural women in particular. Earlier report revealed (Taye Bzuneh, 1996) that only women carried out *enset* processing. Extracting food and fiber from *enset* is highly labor intensive. It was found that it took about 1.5-2 days to fully decorticate, pulverize and knead a matured *enset*. Taye Bzuneh indicated that the orientation of research should be to improve the efficiency of harvesting, extracting food and fiber of *enset* in order to enhance the development of cottage industries at village level.
Achievements

In the early 1970s efforts were made by different individuals and organizations to come up with different processing devices. However, the device, which was originally developed to extract fiber from Abaca in the Philippines, did not save the food element (Taye B. 1996). Atoro’s device, which included chains and sprockets were found difficult to maintain and repair and Milton’s device was not tested (IAR Annual Report, 1977/78)

Institute of Agricultural Research (IAR)
The Engineering Department of the IAR was established in 1977, comprising of Farm Power and Machinery and three other sections. The Farm Power and Machinery
Frie Kelemu

Section started work on two projects namely Water Lifting Devices and *enset*. The work on *enset* started in May 1977. During the 1984/85 research seasons, efforts were made to improve the traditional *enset* decorticating devices. The project came up with a number of *enset* processing devices (Fig. 4), which included an inclined plank/clamp pseudo-stem decorticator, corm graters and *bulla* squeezer. All these were meant to improve the ergonomics, with simple clamping mechanisms at a normal operating position and efficiency. After a number of trials both were achieved. Most of these are currently taken up by the Sodo Rural Technology Center and are distributed to users in the Sidama Region. According to Liyuwork Zewde, 1996, these devices were very much accepted by the women in her study area, because they increased efficiency, reduced wastages and were found comfortable for operation.

The second device of corm grater has some resemblance to that of the carpenter’s jack plane and comprised a set of thin plates in front of the main blade. The efficiency of this device was three times that of the traditional tool, but the sliced material varied in size, which delayed fermentation. Further effort was made to refine the operation of the device and finally an adjustable rotary type blade pulverizer was developed, which was much better than the previous one.

Regarding the *bulla* extraction devices, two flat board squeezer and bucket type squeezer were developed. The first one was developed from two flat boards hinged at the back, but lacked the strength for the intended job.

The second device was made out of metal frame wooden box with sliding piston in it. Many fine holes were drilled on all sides of the wooden box to let out the squeezed *bulla*. This device was found efficient and satisfactory.

**The Former Awassa Agricultural College**

The Awassa Agricultural College, Departments of Agricultural Mechanization and Food Science conducted a study on *enset* processing tools. The study was conducted in a 200 km radius covering the *enset* culture of the Sidama and Wollita zone. The study group finally managed to develop a handy equipment made from local wood without any metallic attaching material (nail). The equipment has three major fitting parts, which are assembled for the operation. It has a decorticating board with a clamp at the upper end, a pulverization chamber at the lower end and a sit with a provision for placing a kneading tray on the other side, fitted at 45 degree angle in slots made on both sides of the main stand. The device was simple and thought to be within the economic reach of the target group. The dimension was within the preferred measurement range, so that once the equipment was set decortications, pulverization squeezing, shredding operations could be done comfortably at ease (Fig. 5). The group report indicated that the women operators at the test sites were very happy with the equipment. Finally, the researchers have proposed to further pursue the work so that the technology will be widely disseminated among the *enset*
farming communities. The research was conducted under a research collaboration project financed by ACA – NORAGRK (Mehtzun et al., 1994)

Current efforts

The research work on the improvement of enset processing devices at the Agricultural Implements Research and Improvement Center (AIRIC) at Melkassa was reinitiated in the late 1990s. A project proposal was developed, reviewed at the different forums and accepted. The proposal had had three components that include: survey, prototype development and evaluation. The work started in September 2000 with a survey. Each component is discussed.
Survey
A survey was conducted in 2000 in two districts to gather information and learn about the *enset* culture with a major focus on the processing technique. The study started with a structured questionnaire where discussion was held with farmers and the district agricultural bureaus officials. While driving from Welkite to Endeber one hardly sees any crops but only *enset*, *Eucalyptus* or open grazing land. The cattle that one observes have small body confirmation and hardly observe any oxen. The area is dominated by hoe culture which limits cultivation to perennial crop like *enset*. The few cattle observed could be partly attributed to the existence of tsetse fly. The Endeber District/Wereda population is mainly dependent on *enset* cultivation for food and as a means of income for buying necessary goods. At Endeber, Yeferenzeige Keble, it was witnessed that in one house hold, the owner had hired about six ladies to decorticate the pseudo-stem and the *amicho* at a rate of two birr per pseudo-stem and two birr per three corm with provision for the necessary daily maintenance i.e. food and coffee for the daily operation on top of the mentioned rate per head. At the time of the study, this practice was the accepted norm in the community. The operators complained that it was indeed a back breaking exercise as the women had to squeeze in a cramped position for the whole day and the need for improvement on the decorticating devices is indisputable. The pseudo-stem-decorr ticating device is a split bamboo beveled at one end, though looked inefficient. There was some reservation on the user's side to replace this device with a metallic part as there was suspicion that it may not enable them to recover the fiber, which fetched them substantial amount of money. The *amicho*-grating device, the *gebangeba* was reported to be tiresome and inefficient. The ladies suggested that any improvement on the devices should include a provision for sitting arrangement during operation.

In other community called Bucha Mender, at Endebir the ladies had the chance of using improved decorticating devices, pseudo-stem decorticator and *bulla* squeezer that were introduced from the Sodo Rural Technology Center. They commented that the clamping arrangement on the decorticator was time consuming and at times it cannot be done from sitting position and because of the flat nature of the plank it was not efficient in fiber recovery. There was mixed filling on the *bulla* squeezer. Some said “it produces finer quality *bullas*, which could be for luxury use, but reduces the volume and the money from selling the product”. Others commented that “it did not totally extract the whole *bullas* and did not produce comparable volume” to their traditional practice. Finally, they opted for the improvement to be done on the above shortcomings and a corm pulverizer be developed as so far they had not seen any device in the area. Similar comments were received from the areas visited at Welkite and Weliso.

Taking the above comments into account the Agricultural Mechanization Research Program of the Melkassa Research Centre proposed to revisit the previous activities.
on *enset* and develop a better pseudostem decorticator and corm pulverizer technologies.

### The First Generation Decorticator
The major modifications were planned mainly on the *enset* decorticator and corm pulverizer. The modified decorticator was provided with a grating board, with a better provision for clamping and better operational position and an efficient scraping tool. The decorticator was fabricated in such a way that it could be handled in the local wood workshop.

The first pulverizer model was designed and fabricated based on the IITA design of cassava grater (Fig. 7). The device had a feeding mechanism and a rotating grater fabricated from galvanized steel. The rotating part was originally made from sheet metal, but later on was replaced with animal horn. The basic material for this specific design was wood and mild steel with the understanding that it will be replaced with corrosion-free material in the final prototype. The grating chamber was fabricated from galvanized sheet and the grater was fabricated from animal horn. This device uses a feed chopped in a rectangular shape for ease of handling. A wheel sprocket drive was added to overcome the drive force requirement (MARC, Progress Report, 2000).

### Testing
First, *enset* corm was brought from Weliso and sliced to manageable size and was tested in the laboratory. Later, the testing material was planted in the Center. It was ready for use in two years after planting. Then, it was cut and removed from the field. It was further cut in rectangular pieces to fit the grating chamber. Data on time taken, output/efficiency, rate/degree of pulverization and down time were recorded (Tables 1 and 2).

#### Table 1. Performance of pedal operated corm pulverizer (Nov 12.2002)

<table>
<thead>
<tr>
<th>Weight (g)</th>
<th>Starting time</th>
<th>Stoppage time</th>
<th>Finishing time (hr)</th>
<th>Total time (min:sec)</th>
<th>Output (kg)</th>
<th>Rate (kg/min)</th>
<th>Unpulverized (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2267</td>
<td>2:05:03</td>
<td></td>
<td>2:06:04</td>
<td>1:06</td>
<td>1.314</td>
<td>1.28</td>
<td>0.790</td>
</tr>
<tr>
<td>3235</td>
<td>2:30:47</td>
<td>4.78</td>
<td>2:36:47</td>
<td>1:13</td>
<td>1.951</td>
<td>1.59</td>
<td>0.719</td>
</tr>
</tbody>
</table>

#### Table 2. Performance of hand operated corm pulverizer

<table>
<thead>
<tr>
<th>Weight (g)</th>
<th>Starting time</th>
<th>Stoppage time</th>
<th>Finishing time (hr)</th>
<th>Total time (min:sec)</th>
<th>Output (kg)</th>
<th>Rate (kg/min)</th>
<th>Unpulverized (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3953</td>
<td>9:46:45</td>
<td></td>
<td>9:48:45</td>
<td>2:00</td>
<td>2.470</td>
<td>1.25</td>
<td>0.572</td>
</tr>
<tr>
<td>3216</td>
<td>1:47:28</td>
<td>1:49:17</td>
<td></td>
<td>1.49</td>
<td>2.399</td>
<td>1.32</td>
<td>0.628</td>
</tr>
</tbody>
</table>

The first design required relatively higher force, which gave a lower output. A second generation corm pulverizer had a higher force requirement observed in the first design. This was more efficient compared to the first generation. With the new
design it was possible to pulverize at a rate of 0.6 kg/min compared to 0.1 kg/min with the previous generation. It was found efficient and comfortable for the operator. Still the work was further refined and a better result was obtained as indicated in the above tables.

The refinement was mainly on the driving mechanism. A pedal operated pulverizer with a sprocket chain driving mechanism with a saddle like arrangement for the operator as in a bicycle. This provision enabled to exert more force using the legs. This resulted in a higher rate of work (Table 1) compared with the hand operated pulverizer (Table 2).

During testing on farmers' field the farmers complained on the wastage because the unpulverized corm was not acceptable. Thus, there was a suggestion to come up with a device that could accommodate the whole corm in one go (MARC, Progress Reports, 2001/2002). The second model was fabricated by adjusting the cutting clearance and using galvanized steel as the cutting material. A wheel sprocket drive was added to overcome the force requirement observed in the previous design. To reduce cost and overcome corrosion problem, the third generation was fabricated using animal horn as the grating material.

The improved decorticator was fabricated in two versions one suitable for standing position and the other one suited for sitting position. Both were tested in Yem and Girbo with the collaboration of Winrock International. Favorable response was received from the users which encouraged the use of the popularization technology (MARC Progress Report, 2002/2003). It was not easy to get quantified data except qualitative information on the stress it imparts and the rate of decortications and pulverizing by an average person. The pseudo-stem-decorticating device is a split bamboo beveled at one end. The operators here again did not like this device with metallic part, which might not enable them to recover the fiber, which is a good source of income,
Despite the different designs forwarded to the users, farmers opted for a machine that takes up the whole corm in one piece. Therefore, they argued that such a device very well fits to their system and there will be minimal loss. Taking this into account, a fourth generation of decorticator was fabricated using the late Araya Kebede’s design (1984) with a major modification on the feeding mechanism. The results of the studies conducted to date, the major problem has been on the feeding rate during grating, which is usually too much, burdens the operator and lowers the durability of the cutting part. A thorough study was conducted to set the optimum feeding rate, which lessens the load on the operator. A feeding mechanism, which delivers a feeding rate of 2 mm per revolution of the cutting disc was designed. The equipment was fabricated in the workshop and was tested on station and at Areka Research Center in collaboration with the Enset Research team. It was also demonstrated at Chencha in collaboration with World Vision Ethiopia where it was found operational and acceptable. The equipment handled a corm up to 45 cm in diameter and of 60 kg weight in less than an hour. At Chencha the corm was found to be as large as 80 cm in diameter and 100 cm in length. It required to be split into two parts as the diameter was larger, but was found acceptable for the above mentioned diameter and weight classes of corms. Though the pulverizer was found efficient in all the tested areas, farmers still complained on the weight of the equipment and operation technique, as it was different from the way they were used to. They even suggested it to be motorized. Other feedbacks on some left over corm due to the various size of the corm were reported at different sites.
The original prototype was modified to accommodate the whole corm. This was based on field data. The feeding section was made large enough to accommodate corms as large as 40cm in diameter and 60cm in length. A feeding mechanism which delivers at a rate of 2mm per revolution of the cutting disc was designed. The equipment was fabricated in the workshop and was tested on station and on farmer’s field. At Koefele (Fig. 7) and Butajira favorable responses were received from the farmers. A sample weight of 20.798 kgs was pulverized in 11.5 minutes. Efforts were also made to reduce the weight, and the size was increased to accommodate bigger sizes of corm as well.

**Manufacturing**

Four local manufacturers generally involved in general metal works were selected from Butajera and Kofele area in May 2006 and were trained at AIRIC workshop on the manufacturing of the corm pulverizer. As part of the training program they were able to manufacture one prototype in a group (Fig. 8).
Field Demonstration and Feed Backs

The work on the corm pulverizer did not stop at the training of Kofele and Butajira would be manufacturers, but effort was made to introduce the technology to other enset growing areas, in the Ambo Weliso and Weskit areas. Effort was also made to introduce the technology and collect feedback and make the technology more amenable to the communities. In the meantime the improvement work has continued on station.

To reduce the load on the operator, the handle for driving the operating wheel was fabricated with a provision of three different radii of 26 cm (the original), 35 cm and 40 cm, with the assumption that the bigger radius will require less effort from the operator to handle the load. From our observation, on tests made on 5 - 6 May 2009 (Table 3) on corms brought from Kulumsa, a higher rate of pulverization was achieved using the 35 mm radius arm than the 40 cm radius arm, which the users found also, a bit awkward requiring the operator to bend more as the handle tips down in relation to the center.
Table 3. Test result of pulverizing using variable arm length corm pulveizer on Enset Henawa Variety

A) Test results, 5 May 2009

<table>
<thead>
<tr>
<th>Nc</th>
<th>Arm radius (cm)</th>
<th>pulverized weight(Kg)</th>
<th>Time(min: sec)</th>
<th>Operator's weight (kg)</th>
<th>Rate(kg/min')</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>1.346</td>
<td>1:44</td>
<td>80</td>
<td>0.774</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>1.242</td>
<td>1:13</td>
<td>63</td>
<td>1.014</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>1.589</td>
<td>1:33</td>
<td>56</td>
<td>1.019</td>
</tr>
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<td></td>
<td>4.177</td>
<td>4:30</td>
<td></td>
<td>0.923</td>
</tr>
<tr>
<td>1</td>
<td>35</td>
<td>3.127</td>
<td>3:0.4</td>
<td>78</td>
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<tr>
<td>2</td>
<td>35</td>
<td>1.477</td>
<td>1:21</td>
<td>60</td>
<td>1.096</td>
</tr>
<tr>
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<td>35</td>
<td>2.049</td>
<td>1:38</td>
<td>60</td>
<td>1.261</td>
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<tr>
<td>Sum</td>
<td></td>
<td>9.920</td>
<td>10:15</td>
<td></td>
<td>0.969</td>
</tr>
</tbody>
</table>

*Pulveried wt(kg)/Time (min:sec)

**Experience at Tikur Enchiene**

Based on the recommendation of the Ambo Research Center, the team visited and demonstrated the *enset* processing devices to farmers at Tikur Enchiene on 22 May 2008, where both the decorticator and pulveizer were demonstrated and farmers had shared their experiences.

The corm pulveizer was operated by different groups of men, women and young people of both sexes. They have managed to operate the machine and still complained about the effort required to operate it. There was a big difference in the ease of operation compared to the experience at other sites. Finally, there was a recommendation to split it into two parts and pulveize each piece separately. This was done as recommended and the operators found it very easy to handle. This comment was given by one of the women operators who tried the equipment under the two different conditions. Generally a favorable response was given and the pulveizer operated much better on corms of <40cm diameter. A split corm was found easier to handle even in diameter class of >40cm.

**Decorticator**

The decorticator was tested by the women. They found it comfortable for the operation. Comment was given on the clearance of the fixing mechanism, which they recommended to have a low clearance or a tighter fit. They also recommended that the fixing pedal should be placed higher so a tighter grip is attained.
Bui, Sodo District July 30-31, 2009

Demonstration was conducted at Bui, Sodo district in Gurage zone from July 30-31 in collaboration with Self Help NGO group (Table 4 and Fig. 9). The enset decorticator, corm pulverizer and bulla squeezer were demonstrated to a women group comprising of sixteen women. Their responses were positive for the decorticator and pulverizer. They commented that the decorticator takes more time and the scrapping blade needs to protrude out so that it will be effective in scrapping in any position. Comments were given to modify it so that it will have provision for scrapping in the standing position as well. They commented that a simple rope hole arrangement could be good enough to hold the enset sheath in place. The Self Help group asked for some standing type decorticators, which were made ready at the workshop and extended to them on payment basis.

The corm pulverizer was demonstrated to the group using a 45 cm- length and a diameter of 20-30 cm corm. Most of the ladies had shared their experiences and did not have much complaint on the ease of operation. They commented that the corm was pulverized to a fine degree and would have liked it to be less fine or coarse. They were told that this could be adjusted by changing the size of the blade serration to achieve a fine or coarse degree of pulverized corm. They also commented that it should have a better provision for mobility, so that they can easily transport it from one place to the other.

Table 4. Field demonstration results of corm pulverizer at Bui town

<table>
<thead>
<tr>
<th>No</th>
<th>Diameter (cm)</th>
<th>Pulverized weight (kg)</th>
<th>Arm radius (cm)</th>
<th>Time (min:sec)</th>
<th>Rate (kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>35</td>
<td>1:37</td>
<td>0.743</td>
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<tr>
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<td>35</td>
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<td>1:5</td>
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</tr>
<tr>
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<td>1.2</td>
<td>35</td>
<td></td>
<td>1:8</td>
<td>1.058</td>
</tr>
<tr>
<td>4</td>
<td>1.0</td>
<td>35</td>
<td></td>
<td>1:10</td>
<td>0.857</td>
</tr>
<tr>
<td>5</td>
<td>1.6</td>
<td>35</td>
<td></td>
<td>1:20</td>
<td>0.959</td>
</tr>
<tr>
<td>6</td>
<td>2.0</td>
<td>35</td>
<td></td>
<td>1:30</td>
<td>1.333</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.046</td>
</tr>
</tbody>
</table>
Current and Future Directions

The Agricultural Mechanization Research Process is currently working on simplifying the operation and mobility of corm pulverizer devices as recommended by farmers. The cutting disk is now designed with its major mass concentrating at its outer rim (Figure 10), thus drastically reducing its weight. Similar works are being done on the mobility aspect as well.

Disseminated Technology

Some decorticators are delivered to users in recent years. Thirty *enset* decorticators, one corm pulverizer and 16 decorticating blade with the holder were sold to
individuals and groups through Self Help Development International in 2008/09 seasons.

**Gaps and Gap Analysis**

Generally the processing of *enset* has been a back breaking exercise and a very difficult task for the rural women. In spite of the fact that efforts have made by different groups, still there was the urgent need to come up with better processing equipment. The women involved in the operation recommended for improvement of the overall *kocho* processing methods in order to save energy, time and to make it more hygienic.

Though substantial amount of work has been done to simplify and ease the operation, it is still difficult to say that it is amenable to all working age and weight groups. The corm pulverizer is not versatile enough to be moved from one village to another. The *bulla* squeezer is not big enough to handle larger charge. All the processing gadgets do not have any provision for automatic operation. Farmers have commented that the degree of pulverization need to be as required by the user and therefore, a mechanism is needed to be in place to control the outcome.

Though *enset* is an important crop, the demonstration and extension work has been minimal to effect the dissemination of the technology among the user communities. The participation of the private sector especially manufacturers is negligible, which otherwise would have been instrumental in the multiplication and dissemination of the technology. The insignificant level of involvement of financial institutions such as unions is a major gap which needs serious attention.

The emphasis given to capacity building, staff training and strengthening the research on the post harvest engineering aspect is far from adequate. A number of steps ought to be taken to further alleviate the problem of processing and hence making a healthy product so that people involved in the production, processing and marketing will all be beneficiaries.

**Discussion and Recommendation**

*Enset* is a very important life saving crop for over 20 million people in the country. However, its processing aspect has not been given due consideration that allocation of fund, training of personnel and strengthening of the engineering wing, which is instrumental in the delivery of the processing technology are negligible.

Despite these, the research system needs to build momentum and address the current issues at hand. The issues raised on efficiency of gripping, the *enset* decorticator, the weight and mobility questions on the pulverizer need to be
addressed as soon as possible as priority issue. The demonstration work on the available technologies should be aggressively pursued to create awareness among the enset growing communities at large. Private manufacturers such as micro enterprises need to be trained and be involved in the manufacturing of the newly improved devices. The research system need to be strengthened, staff need to be trained in post-harvest engineering science and adequate financial support be provided to scale out and deliver the required technology to make a difference in the livelihood of the enset farmers and the population at large.

References

Research Achievements and Experiences on Enset Food Products

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Abstract

Different researches were conducted by different scholars on enset crop processing and utilization. In this paper major findings are reviewed. In Ethiopia more than 20 percent of the population depends upon enset as a source of food, means of cash earning, insurance against hunger, feed and fiber for industrial use. Enset is a starchy crop rich in carbohydrate and some minerals (Fe, Ca and Zn). It is however very poor in fat, protein, and vitamin A. The two popular foods prepared from enset by fermentation process are kocho and bulla. The fermentation process is initiated by Leuconostoc mesenteroides bacteria. Kocho become easily contaminated by microorganisms when removed from the fermenting pits. Spoiled kocho and bulla had high counts of aerobic mesophilic bacteria, Micrococcus and Bacillus species. The protein density and vitamin A of kocho and bulla can be increased by addition of legumes and pumpkin pulp, respectively. The yield of enset in terms of dry matter production and energy production per unit space and time is much higher than cereal and other root and tuber crops. Starch, in small amount, from enset is currently produced industrially by a local factory and its chemical composition, physicochemical properties, and amylase content have been analyzed and documented. Modernization of fermentation process of enset and other traditional foods must be given due attention. Food fortification and supplementation of enset food with nutrient or protein rich foods must be developed. The bio-availability, bio-efficacy, other nutritional and functional properties of the enriched product should be studied. The already achieved research outputs particularly in the area of food supplementation at the enset growing areas for vulnerable groups should be sensitized. There should be an extensive research and development work on local production of starch from indigenous crops.

Keywords: Enset, Kocho, Bulla, Fermentation, processing and utilization, starch
Introduction

Root and tuber crops are widely cultivated in Southern Ethiopia that supports a considerable portion of the country's population as source of food. Prominent among these are: potato (*Solanum tuberosum* L.), sweet potato (*Ipomoea batatas* L.), *enset* (*Ensete ventricosum* (Welw.), Chessman), Godere (*Colocasia esculenta* L.), yams (*Dioscorea spp.*), Ethiopian dinch (*Coleus parviflorus*), koteharrie (*Diaspora bulbiferous*) and anchote (*Coccinia abyssinica*). *Enset*, anchote and some yams are endemic to Ethiopia (Addis, 2005).

*Enset* belongs to the order Scitamineae, family Musaceae. The genus *Ensete* comprises of 5-7 species, half of which are African, the other half are Asian in origin (Taye, 1984). *Enset* is related to and resembles the banana plant and is produced primarily for the large quantity of carbohydrate-rich food. Both *enset* and banana have an underground corm, a bundle of leaf sheaths that form the pseudo-stem, and large leaves. *Enset*, however, is usually larger than banana. The leaves are more erect than those of a banana plant, have the shape of a lance head and about five meters long and nearly one meter wide. Its pseudo-stem widens at the base to a circumference of 1.5 to 3.0 m. Depending on the variety and ecological condition of its cultivation, the pseudo-stem length ranges from 2 to 5 m (Taye, 1984; Brandt et al., 1997). About 20 percent of the population of the country, concentrated in the highlands of Southern and Southeastern Ethiopia, depends upon *enset* for human food, fiber, animal feed, construction materials, medicines, means of earning cash income and insurance against hunger.

*Enset* is one of the potential indigenous crops for food production (Taye, 1984; Endale, 1991) and can be grown everywhere in Ethiopia. According to several authors (Smeds, 1955 and Taye et al., 1967), the *enset* cultivation system is economically viable and is one of the few successful indigenous crops that have become sustainable in the agricultural systems. It is sustainable and has been providing food for humans for generation from the same plot and maintains the quality of life of the people. It grows in a wide range of environmental conditions. Even though it is grown in many administrative regions, the dwellers of the Central and Southwestern parts of Ethiopia (Sidamo, Shoa, Keffa, Gamo Goffa and Illubabor administrative regions) are the only people that use *enset* as a staple and co-staple crop (Simmonds, 1958; Addis, 2005).

The plant is most productive if harvested at maturity, but can be harvested at any time after about 2 years of age (Kefale and Sandford, 1991). The same authors expressed the yield potential of *enset* at maturity in Welatva to yield 1.3 - 3.5 more edible energy per hectare per year than peasant-grown maize, which yields about 3000 kg grain per hectare. The edible product is high in energy (190 Calories/gram) but low in crude protein (2-5% by weight).
Enset provides fiber as a byproduct of decorticated leaf sheaths. The fiber has excellent structure, and its strength is equivalent to the fiber of abaca, a world-class fiber crop (Taye and Abraham 1967). About 600 tons of enset fibers per year are sent to local factories. In rural areas the fiber is used to make sacks, bags, ropes, cordage, mats, construction materials (such as tying materials that can be used in place of nails), and sieves (Brandt et al., 1997). Fresh enset leaves are used as bread and food wrappers, serving plates, and pit liners to store kocho for fermentation and future use. During enset harvesting the leaves are used to line the ground where processing and fermentation take place. The dried petioles and midribs are used as fuel, and to make mats and tying materials for house construction. The pulp from the dried leaf sheaths, petioles, and midribs is used as cleaning rags and brushes, baby cushions/diapers, and cooking pot stands. Dried leaf sheaths are used as wrappers for butter, kocho, and other items to transport to local markets. Enset leaves are an important cattle feed, especially in the dry season when grasses are scarce. Leaves are carried into the house for stall feeding of cattle during the nighttime.

Particular clones (or varieties) and parts of enset plants are used medicinally for both humans and livestock to cure bone fractures, broken bones, childbirth problems (i.e., to assist in the discharging of the placenta), diarrhea, and birth control (as an abortifacient) (Brandt et al., 1997).

Achievements Made on Enset Processing, Utilization and Improving its Nutritional Quality

processing and utilization of enset products

The optimal harvest times for enset plant depend on the specific cultivars. Enset if harvested too young has a low starch content and if harvested too late (after fructification) it has a reduced amount of starch. The maximum output is obtained when the plant is fully mature and ripe for harvest which is indicated by the emergence of the inflorescence. Another indication is the emergence of fresh roots from the base above the soil surface. The period of maturity depends on variety, climate and soil fertility. Enset matures from 4-6 years after planting, whereas, for amicho it would be ready any time at one year after planting in the field.

The preparation of enset for processing is a very time-consuming and tedious work. By social custom, almost all the operations connected with enset processing are the exclusive responsibility of women in the family.

The major foods obtained from enset are kocho, bulla and amicho. Kocho is the bulk of the fermented starch obtained from the mixture of the decorticated (scraped) leaf sheaths and grated corm (underground stem base). Kocho needs a lengthy period of processing and preparation. The first stage involves removing the leaf stalks and grating of the corm. Then, the fibers are separated out and the pulp is crushed to extract the starch. This is put in a pit about 1.5 m deep and 1 m diameter, wrapped airtight with enset leaves before being packed down with stones. It is then allowed to
ferment - a process, which may last anytime from 4 months to three years. The pit is opened at intervals to allow aeration, and the enset leaves are replaced. This is repeated until the desired fermentation quality is reached or when it is needed. After fermentation the product is chopped to reduce the fiber size and then sieved. Finally, the fermented starch is dried and treated as flour. Kocho can be stored for long periods of time without spoiling. The quality of kocho depends on the age of the harvested plant, the type of clone (variety) and the harvesting season. Moreover, within one plant, the quality is influenced by the part of leaf sheath and corm processed. The preferred type is white in color and is obtained from the innermost leaf sheaths and inner part of the corm, while the lowest grade is blackish and is obtained from the outer leaf sheath and corm. Although many different dishes are prepared from kocho, a pancake like bread is the most common, which is eaten with milk and cabbage. It is also extremely popular at restaurants that served kitfo - a traditional food (finely minced uncooked or rarely cooked meat mixed with spicy butter). The other quality determinants of kocho are the skill of the processor (woman) and the care taken in processing and time of processing, where dry season is considered the best.

Appropriate mix of varieties and proper covering and protection of the fermentation pit are also factors that determine the quality of kocho.

Bulla is obtained through passing the following processing stages: scraping the leaf sheath, peduncle, and grated corm into a pulp; squeezing liquid containing a starch from the pulp; allowing the starch to concentrate into a white powder and rehydrating with water. It is considered as the best quality enset food and is obtained mainly from fully matured enset plants. Bulla can be prepared as a pancake, porridge, or dumpling.

Amicho is the boiled enset corm, usually of a younger plant. Enset plants may be uprooted for preparing meals quickly if the amount of enset harvested is insufficient, or for special occasion. The corm is boiled and consumed in a manner similar to the preparation method for other root and tuber crops. Certain varieties are selected for their amicho production.

Among the main processing steps of making kocho and bulla, fermentation is the key operation. Therefore some scholars conducted research activities relating to understanding the type of microorganisms employed to necessitate the fermentation process and during the fermentation period; identifying microorganisms responsible for the spoilage and deterioration of processed enset products, investigating the effect of fermentation on the chemical composition (nutritional content/value) and the effect of fermentation on anti-nutritional content of enset.

Gashe (1987) is one of the scholars who extensively studied and described the microbiology of kocho fermentation. In his report, a microorganism named
Leuconostoc mesentroides initiated the fermentation process and dominated the lactic flora with counts of $10^7$ cfu/g on day 8. The pH of the fermentation mass dropped from 6.5 to 5.8 in 8 days. Lactobacillus coryneformis and Lactobacillus plantarum dominated thereafter and further reduced the pH to 4.2 after 50 days. Spore formers were present at levels of $\leq 10^6$ cfu/g during the first 15 days. Generally, the population of Clostridium spp. was two to five times more abundant than Bacillus spp. C. sartidium butyricum, C. beijerinckii, C. sticklandi, B. subtilis, B. megaterium, B. licheniformis and B. cereus were among spore formers which appeared to show active growth in fermenting Kocho. Yeast reached their highest counts of $10^4$ cfu/g between 22 and 43 days and the yeast flora consisted of the Trichosporon, Torulopsis Rhodotorula and Candida.

Gashe also reported that kocho become easily contaminated by microorganisms when removed from the fermenting pits and the major spoilage fungi belonged to Penicillium, Trichoderma and Chaetomium species. In addition, bacterial species belonging to Leuconostoc, Pseudomonas Bacillus and Erwinia were isolated from slimy kocho. The microbial spoilage was manifested in the form of discoloration.

Mogessie and Yewelsew (1996), have also studied the microbial load of kocho and bulla sold at Hawassa open market. They observed that the products did not undergo appropriate fermentation and had pH values around neutral. Kocho and bulla had high counts of aerobic mesophilic bacteria and yeasts ($10^3$ cfu/g). Coliform counts were markedly higher in bulla ($10^5$ cfu/g) than in kocho ($10^3$ cfu/g). Counts of enterococci, in both products, ranged between $10^4$ and $10^5$ cfu/g. Micrococci and Bacillus spp. dominated the aerobic bacterial flora. Among the yeast species, Rhodotorula glutinis, Kveromyces marxianus and Pichia membranefaciens were isolated from most samples. As kocho and bulla appeared to be processed in unhygienic conditions, unfermented products are likely to spoil easily.

They also observed that when these products were stored at room temperature in a loosely wrapped condition, both products had undesirable odor, slimy surface and dark discoloration after eight days. Spoiled kocho and bulla had high counts of aerobic mesophilic bacteria (about $10^{10}$ cfu/g) with Micrococcus and Bacillus species dominating the spoilage flora. Psychrophilic microorganisms consisting of bacteria and molds were isolated at levels of $>10^4$ cfu/g and mold spores caused dark discoloration. Microorganisms active in starch hydrolysis, proteolysis and lipolysis were encountered in the products at varying frequencies. Tightly wrapped samples, which served as control, did not show any detectable spoilage in terms of odor, consistency or color. The fermentation of kocho not only modifies and improves the quality, but also aids in its preservation. The presences of antibiotic-like substances in kocho and their inhibitory activity on Gram-negative bacteria such as Salmonella, Klebsiella may have far reaching significance as in gastrointestinal tract microflora.
and infection. Hence, detailed studies on the chemicals produced by Lactic Acid Bacteria during fermentation should be carried out (Nigatu and Gashe, 1994).

The presence of appreciable levels of oxalic acid, trypsin inhibitors (TI) and tannins in *enset* that contribute the major component of the diet of the South and South Western people of Ethiopia is likely limit its utilization. However, natural fermentation of *enset* markedly reduced the content of trypsin inhibitor and tannins thus enhance the digestibility of *kocho* protein and bioavailability of minerals (Kelbessa *et al.*, 1997).

<table>
<thead>
<tr>
<th>Period (week)</th>
<th>Tannin mg/100g</th>
<th>TIA TIU/g</th>
<th>Oxalic acid mg/100g</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>676 ±41</td>
<td>8356 ±11</td>
<td>230 ±32</td>
</tr>
<tr>
<td>1</td>
<td>644 ±34</td>
<td>8137 ±120</td>
<td>228 ±23</td>
</tr>
<tr>
<td>2</td>
<td>440 ±23</td>
<td>7956 ±177</td>
<td>225 ±24</td>
</tr>
<tr>
<td>3</td>
<td>430 ±31</td>
<td>6870 ±123</td>
<td>224 ±22</td>
</tr>
<tr>
<td>4</td>
<td>422 ±30</td>
<td>5184 ±130</td>
<td>220 ±21</td>
</tr>
<tr>
<td>5</td>
<td>390 ±32</td>
<td>4288 ±137</td>
<td>224 ±19</td>
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<tr>
<td>6</td>
<td>331 ±18</td>
<td>4079 ±112</td>
<td>235 ±32</td>
</tr>
<tr>
<td>7</td>
<td>333 ±21</td>
<td>3924 ±110</td>
<td>220 ±34</td>
</tr>
</tbody>
</table>

Source: Kelbessa Urga *et al.*, (1997)

The bases and corms of *enset* show enzymatic browning reaction when cut and exposed to air. This can occur with the corm in the fresh state, after storage or when physiologically damaged. The cause of this process could be associated with the reaction of phenolic substances (Kelbessa *et al.*, 1997).

The other research areas conducted by the scholars was whether the *kocho* yield of *enset*, in terms of weight and energy, under different crop establishment methods has more advantages than other crops. Most of the previous reports published were on fresh yield of fermented *kocho* and were based on survey works. In addition, they lacked information on the age of plants harvested, stages of transplanting and the duration of the fermentation periods of the products (Bezuneh, 1984; Makiso, 1976, CSA, 1997). The yield report shows 23.5 (Bezuneh, 1984), 30.6 (Makiso, 1976) and 30.15 (CSA, 1997) kg of *kocho* per plant. The yield is much lower than the yield reported by Admasu and Struik (2001), who compared the performance of *enset* yield with the yield of other major starch crops grown in the country. In this study maximum fresh yield of *kocho* after 88 days of fermentation from *enset* plants transplanted once (at 130 weeks after first transplanting), from *enset* transplanted twice and trice (at 234 weeks after first transplanting) were 25.9, 54.1 and 37.1 kg/plant, respectively (Table 2).
Table 2: Fresh weight (kg/plant) of fermented kacho harvested at different weeks after removal from the mother corm for different times of transplanting and leaf pruning treatments.

<table>
<thead>
<tr>
<th>Transplanting</th>
<th>Leaf pruning</th>
<th>Weeks after removal from mother corm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(B)</td>
<td></td>
</tr>
<tr>
<td>Once</td>
<td>Without</td>
<td>104 130 156 182 208 234 260</td>
</tr>
<tr>
<td></td>
<td>With</td>
<td>18.6 25.9 20.3</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>16.6a 21.4a 19.1a</td>
</tr>
<tr>
<td>Twice</td>
<td>Without</td>
<td>3.3 12.5 13.5 22.5 27.5 54.1 28.5</td>
</tr>
<tr>
<td></td>
<td>With</td>
<td>4.2 12.0 16.5 24.8 53.9 30.5</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>3.8b 12.3b 15.0b 19.6a 26.1a 54.0a 29.5</td>
</tr>
<tr>
<td>Thrice</td>
<td>Without</td>
<td>1.7 3.3 3.9 9.5 15.5 37.1 31.0</td>
</tr>
<tr>
<td></td>
<td>With</td>
<td>1.5 2.6 4.3 10.0 12.5 29.9 26.0</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>1.6c 2.9c 4.1c 9.6 14.0b 33.5b 28.5</td>
</tr>
<tr>
<td></td>
<td>Without</td>
<td>7.9 13.9a 12.5 16.0 21.4 45.6 29.8</td>
</tr>
<tr>
<td></td>
<td>With</td>
<td>6.7 10.5b 12.9 13.3 18.6 41.9 28.3</td>
</tr>
<tr>
<td>Grand mean</td>
<td></td>
<td>7.3 12.2 12.7 14.7 20.1 43.8 29.0</td>
</tr>
<tr>
<td>CV (%)</td>
<td></td>
<td>21 29 14 23 17 23 22</td>
</tr>
<tr>
<td>P or LSD (0.05) A</td>
<td></td>
<td>1.6*** 3.8*** 1.9*** 3.8** 3.9** 11.4** Ns</td>
</tr>
<tr>
<td>P or LSD (0.05) B</td>
<td></td>
<td>Ns 3.1* ns Ns ns Ns Ns Ns</td>
</tr>
<tr>
<td>P or LSD (0.05) AxB</td>
<td></td>
<td>2.3* 5.3* 2.7*  P&lt;0.09 ns Ns Ns</td>
</tr>
</tbody>
</table>

Note: ns, *, **, and*** indicate non-significant, significant at p<0.05, 0.01, and 0.001, respectively (F test). Different letters within a column indicate significant difference at p<0.05, according to Duncan's Multiple Rang Test

Source: Admasu and Struik, (2001)

Enset transplanted once, twice and thrice produced much more edible dry matter per unit space and time compared to the other main crops (Table 3). The edible dry matter production rate of enset plants transplanted twice and trice was much more compared to all other crops, whereas the difference between enset plants transplanted once and sweet potato or taro in terms of edible dry matter production rate was very similar. The average edible dry matter production rate of enset from the three crop establishment methods was about 133 and 69 % higher than the average values for cereals and root and tuber crops, respectively. The dry matter percentage of fermented kacho was almost comparable to that of taro, yam and sweet potato.
Table 3. Average yield and edible dry matter production rates of major crops grown in Ethiopia as compared with enset under different crop establishment methods

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield (g/m²) Based on average spacing</th>
<th>Edible portion (%)</th>
<th>Dry matter (%)</th>
<th>Edible dry matter (g/m² pre harvest)</th>
<th>Growth period (days)</th>
<th>Edible dry matter (g/m²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enset</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transplanted once</td>
<td>3886</td>
<td>80</td>
<td>32</td>
<td>944</td>
<td>730</td>
<td>1.29</td>
</tr>
<tr>
<td>Transplanted twice</td>
<td>14958</td>
<td>80</td>
<td>30</td>
<td>3590</td>
<td>1643</td>
<td>2.19</td>
</tr>
<tr>
<td>Transplanted thrice</td>
<td>11817</td>
<td>80</td>
<td>29</td>
<td>2742</td>
<td>1643</td>
<td>1.67</td>
</tr>
<tr>
<td>Average enset</td>
<td>10154</td>
<td>80</td>
<td>30</td>
<td>2425</td>
<td>1339</td>
<td>1.72</td>
</tr>
<tr>
<td>Teff</td>
<td>94</td>
<td>100</td>
<td>89</td>
<td>83</td>
<td>120</td>
<td>0.69</td>
</tr>
<tr>
<td>Barley</td>
<td>104</td>
<td>100</td>
<td>87</td>
<td>90</td>
<td>150</td>
<td>0.60</td>
</tr>
<tr>
<td>Wheat</td>
<td>147</td>
<td>100</td>
<td>87</td>
<td>128</td>
<td>150</td>
<td>0.85</td>
</tr>
<tr>
<td>Maize</td>
<td>159</td>
<td>100</td>
<td>80</td>
<td>127</td>
<td>150</td>
<td>0.85</td>
</tr>
<tr>
<td>Sorghum</td>
<td>126</td>
<td>100</td>
<td>85</td>
<td>107</td>
<td>150</td>
<td>0.71</td>
</tr>
<tr>
<td>Finger millet</td>
<td>97</td>
<td>100</td>
<td>89</td>
<td>86</td>
<td>120</td>
<td>0.72</td>
</tr>
<tr>
<td>Average of cereals</td>
<td>121</td>
<td>100</td>
<td>86</td>
<td>104</td>
<td>140</td>
<td>0.74</td>
</tr>
<tr>
<td>Irish potato</td>
<td>713</td>
<td>85</td>
<td>20</td>
<td>121</td>
<td>120</td>
<td>1.01</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>821</td>
<td>85</td>
<td>30</td>
<td>209</td>
<td>150</td>
<td>1.40</td>
</tr>
<tr>
<td>Cassava</td>
<td>688</td>
<td>85</td>
<td>40</td>
<td>228</td>
<td>270</td>
<td>0.85</td>
</tr>
<tr>
<td>Taro</td>
<td>932</td>
<td>85</td>
<td>30</td>
<td>237</td>
<td>210</td>
<td>1.13</td>
</tr>
<tr>
<td>Yam</td>
<td>750</td>
<td>85</td>
<td>27</td>
<td>172</td>
<td>270</td>
<td>0.64</td>
</tr>
<tr>
<td>Average of root and tuber crops</td>
<td>781</td>
<td>85</td>
<td>29</td>
<td>177</td>
<td>193</td>
<td>1.01</td>
</tr>
</tbody>
</table>


The average energy production rates of enset under different crop establishment methods and main crops (Table 3) are calculated using food composition tables. Twice transplanted enset plants increased energy production rate by 80 and 27% compared to once and thrice transplanted, respectively. Enset plants transplanted once, twice and thrice produced much more energy per unit space and time compared to other high energy producing crops (Table 4). The average energy production rate from the three crop establishment methods was about 286 and 172% higher than that of cereals, root and tuber crops, respectively.
Table 4: Energy production rates of major crops as compared with the energy production rates of enset under different crop establishment methods.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Energy yield (g/m²)</th>
<th>KJ/100 g of edible yield</th>
<th>Energy production (KJ/m²)</th>
<th>Energy production rate (KJ/m²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enset Transplanted once</td>
<td>2949</td>
<td>883</td>
<td>26040</td>
<td>35.67</td>
</tr>
<tr>
<td>Enset Transplanted twice</td>
<td>11966</td>
<td>883</td>
<td>105660</td>
<td>64.31</td>
</tr>
<tr>
<td>Enset Transplanted thrice</td>
<td>9454</td>
<td>883</td>
<td>83479</td>
<td>50.81</td>
</tr>
<tr>
<td>Average enset</td>
<td>8123</td>
<td>883</td>
<td>71726</td>
<td>50.26</td>
</tr>
<tr>
<td>Teff</td>
<td>94</td>
<td>1485</td>
<td>1396</td>
<td>11.63</td>
</tr>
<tr>
<td>Barley</td>
<td>104</td>
<td>1552</td>
<td>1614</td>
<td>10.76</td>
</tr>
<tr>
<td>Wheat</td>
<td>147</td>
<td>1494</td>
<td>2196</td>
<td>14.64</td>
</tr>
<tr>
<td>Maize</td>
<td>159</td>
<td>1569</td>
<td>2495</td>
<td>16.63</td>
</tr>
<tr>
<td>Sorghum</td>
<td>126</td>
<td>1502</td>
<td>1192</td>
<td>7.95</td>
</tr>
<tr>
<td>Finger millet</td>
<td>97</td>
<td>1469</td>
<td>1425</td>
<td>11.88</td>
</tr>
<tr>
<td>Average of cereals</td>
<td>121</td>
<td>1512</td>
<td>1720</td>
<td>12.25</td>
</tr>
<tr>
<td>Irish potato</td>
<td>606</td>
<td>431</td>
<td>2612</td>
<td>21.76</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>698</td>
<td>569</td>
<td>3972</td>
<td>26.48</td>
</tr>
<tr>
<td>Cassava</td>
<td>571</td>
<td>640</td>
<td>3654</td>
<td>13.53</td>
</tr>
<tr>
<td>Taro</td>
<td>792</td>
<td>519</td>
<td>4110</td>
<td>19.57</td>
</tr>
<tr>
<td>Yam</td>
<td>638</td>
<td>464</td>
<td>2960</td>
<td>10.96</td>
</tr>
<tr>
<td>Average of root and tuber crops</td>
<td>661</td>
<td>525</td>
<td>3462</td>
<td>18.46</td>
</tr>
</tbody>
</table>


**Nutritional composition of enset**

The main feature of enset foods is their high energy value (1410–1950 kJ per 100 g dry matter of kocho and 1580–1850 kJ per 100 g dry matter of bulla), derived almost entirely from carbohydrate. Fresh kocho contains 47–62 g moisture per 100 g fresh weight. The approximate composition of kocho per 100 dry matters is: 1.1–2.8 g protein, 0.2–0.5 g fat, 95–98 g carbohydrates, 2.3–6.2 fiber g, 1.7 g ash, 60 mg calcium, 68 mg phosphorus, 7 mg iron, 0.06 mg thiamine, 0.08 mg riboflavin, 0.6 mg niacin. The moisture content of bulla ranges from 44–55 g per 100 g fresh material. Table 6 shows that the approximate composition of bulla per 100 g dry matter is: 0.4–0.8 g protein, 0.2–0.4 g fat, 93–98 g carbohydrates, 0.6–0.8 g fiber, 0.2 g ash, 91 mg calcium, 44 mg phosphorus, 5.8 mg iron, thiamine 0.02 mg thiamin, 0.2 mg niacin (Agren et al., 1968, EHNRI, 1997).

Minaleshewa and Chandravanshi (2008) studied commercially available enset products (kocho and bulla) for major, minor and trace minerals and they showed that, the concentration of K was highest followed by Na, Ca, and Mg in both foodstuffs. From trace elements analyzed, Zn was found to be highest next to Fe. Generally, kocho contained higher concentration of the mineral nutrients compared to bulla. Thus, kocho and bulla are rich in calcium and zinc compared to other similar foodstuffs and contains comparable concentration of calcium, iron and manganese. The toxic metals cadmium (Cd) and lead (Pb) were not detected in both types of foodstuffs.
Wolde-Gebriel et al. (2006) reported that *bulla* is more energy rich (204 Cal per 100g) than *kocho* (156 Cal per 100 g) on dry weight basis. All foods have low protein content (4-22 g/kg) and no vitamin A. If correspondingly the energy values for food grain like *tef*, wheat, barley and corn are estimated at 350 Cal per 100 g dry weights. The food energy per unit weight of *bulla* and *kocho* are only 57% and 45% of the food grains. The protein quality of *kocho* is poor due to low content of essential amino acids such as methionine and isoleucine (Besrat et al., 1979). It is obvious that such low levels of protein, if not supplemented from other sources, are inadequate to meet the minimal protein requirement of human.

Yewelsew et al. (2007) analyzed the zinc, iron, calcium and phytate content (mg per 100 g fresh weight) and the phytate: zinc and phytate: iron molar ratios of the perishable foods prepared from the major plant-based staples of Sidama region: *enset* (*E. ventricosum*), *tef* (*E. tef*) and maize (*Zea mays* L.). There was a wide range in the mineral content of the three starchy fermented foods prepared from *enset*. Zinc content ranged from 0.07 mg/100 g for *bulla* 1.33 mg/100 g fresh weight for *amicho*. *Amicho*, followed by *bulla*, had a much lower content of calcium than fermented baked *kocho*. Indeed, fermented, baked *kocho* had the highest level of calcium of all the perishable, prepared foods analyzed (Table 5).

Of the three types of fermented *tef injera* samples analyzed, only one had a very high iron content (71 mg/100 g) compared to 7.0 mg/100 g for the other two *injera* samples and 3.4 mg/100 g for unleavened corn bread. The zinc content of all the prepared cereal products was very similar, ranging from 0.93 mg/100 g for *injera* prepared from a mixture of red and white *tef* to 1.75 mg/100 g for *injera* prepared from red *tef*. The calcium content of the unleavened corn bread was lower than that of fermented *tef injera*. All the starchy fermented foods prepared from *enset* and fermented *tef injera* had lower levels of IP5+IP6 than the unleavened corn bread. Only unleavened corn bread had a calculated phytate: zinc molar ratio above 15, whereas corn bread, boiled kidney beans and *injera* prepared from white *tef* had phytate: iron ratios above 1.0.
Table 5. Median (1st, 3rd quartile) zinc, iron, calcium and phytate contents (mg/100 g fresh weight) of perishable prepared foods from Sidama, Ethiopia

<table>
<thead>
<tr>
<th>Food type</th>
<th>Moisture (g/100 g)</th>
<th>Zinc (mg/100 g)</th>
<th>Iron (mg/100 g)</th>
<th>Calcium (mg/100 g)</th>
<th>Phytate (mg/100 g)</th>
<th>Phy:Zn</th>
<th>Phy:Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enset starchy foods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kocho, fresh: pulp (n=3)</td>
<td>86 (82, 96)</td>
<td>0.09 (0.08, 0.15)</td>
<td>1.1 (0.8, 1.6)</td>
<td>52 (46, 60)</td>
<td>7 (6, 9)</td>
<td>8.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Kocho, fermented: pulp, baked (n=16)</td>
<td>36 (25, 44)</td>
<td>0.52 (0.32, 0.72)</td>
<td>6.2 (3.6, 10.1)</td>
<td>162 (140, 226)</td>
<td>n.d.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulba: desiccated juice from enset pulp (n=4)</td>
<td>57 (54, 58)</td>
<td>0.07 (0.05, 0.09)</td>
<td>4.8 (3.6, 6.5)</td>
<td>44 (40, 47)</td>
<td>n.d.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amicho: decorticated tuber before fermentation (n=4)</td>
<td>76 (71, 77)</td>
<td>1.33 (1.03, 1.61)</td>
<td>0.7 (0.6, 1.1)</td>
<td>25 (24.29)</td>
<td>0.9 (0.2, 13.0)</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Cereals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tef dough unfermented (n=3)</td>
<td>57 (35, 66)</td>
<td>1.36 (1.19, 1.96)</td>
<td>6.8 (6.7, 26.4)</td>
<td>65 (51, 91)</td>
<td>139 (136, 144)</td>
<td>8.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Injera: from fermented white tef dough (n=1)</td>
<td>71.6</td>
<td>1.11</td>
<td>6.8</td>
<td>36</td>
<td>102</td>
<td>9.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Injera: from fermented white and red tef dough (n=1)</td>
<td>67.8</td>
<td>0.93</td>
<td>7</td>
<td>35</td>
<td>36</td>
<td>3.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Injera: from fermented red tef dough (n=1)</td>
<td>55.5</td>
<td>1.75</td>
<td>70.9</td>
<td>76</td>
<td>117</td>
<td>6.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Corn bread, unleavened (n=16)</td>
<td>35 (29, 49)</td>
<td>1.66 (1.36, 1.84)</td>
<td>3.4 (3.0, 5.5)</td>
<td>14 (12, 20)</td>
<td>394 (366, 442)</td>
<td>21.6</td>
<td>5.4</td>
</tr>
<tr>
<td>Legumes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kidney beans, red: whole, dried, boiled (n=7)</td>
<td>38 (34, 59)</td>
<td>1.52 (1.23, 1.94)</td>
<td>2.7 (2.4, 4.3)</td>
<td>69 (55, 96)</td>
<td>219 (176, 253)</td>
<td>14.6</td>
<td>6.0</td>
</tr>
</tbody>
</table>

N= number of food samples in each food type
Source: Yewelsew, A. et al., 2007
Table 6. Composition of various enset products in terms of 100 grams of edible portion

<table>
<thead>
<tr>
<th>Enset (Ensete ventricosum) product</th>
<th>Energy (calories)</th>
<th>Moisture (%)</th>
<th>Nitrogen (g)</th>
<th>Fat (g)</th>
<th>CHO (g)</th>
<th>Fiber (g)</th>
<th>Ash (g)</th>
<th>Ca (mg)</th>
<th>P (mg)</th>
<th>Fe (mg)</th>
<th>Thiamine (ug)</th>
<th>Riboflavin (ug)</th>
<th>Niacin (ug)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enset powder</td>
<td>196.00</td>
<td>49.70</td>
<td>0.30</td>
<td>0.90</td>
<td>0.20</td>
<td>47.70</td>
<td>1.20</td>
<td>1.60</td>
<td>77.00</td>
<td>60.00</td>
<td>10.10</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>Bulla powder</td>
<td>180.50</td>
<td>54.90</td>
<td>0.03</td>
<td>0.20</td>
<td>0.10</td>
<td>44.70</td>
<td>0.30</td>
<td>0.10</td>
<td>41.00</td>
<td>20.00</td>
<td>2.60</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Bulla bread</td>
<td>186.10</td>
<td>53.30</td>
<td>0.03</td>
<td>0.30</td>
<td>0.10</td>
<td>46.00</td>
<td>0.30</td>
<td>0.30</td>
<td>45.00</td>
<td>18.00</td>
<td>4.60</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Bulla porridge</td>
<td>80.30</td>
<td>81.00</td>
<td>0.03</td>
<td>0.20</td>
<td>1.10</td>
<td>17.40</td>
<td>0.50</td>
<td>0.30</td>
<td>30.00</td>
<td>10.00</td>
<td>2.60</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Kocho powder</td>
<td>211.10</td>
<td>46.70</td>
<td>0.20</td>
<td>0.60</td>
<td>0.30</td>
<td>51.50</td>
<td>1.20</td>
<td>0.90</td>
<td>32.00</td>
<td>36.00</td>
<td>3.70</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>Kocho bread</td>
<td>219.40</td>
<td>43.70</td>
<td>0.20</td>
<td>1.00</td>
<td>0.20</td>
<td>53.40</td>
<td>1.30</td>
<td>1.70</td>
<td>93.00</td>
<td>43.00</td>
<td>2.40</td>
<td></td>
<td>0.10</td>
</tr>
<tr>
<td>Kocho porridge</td>
<td>90.60</td>
<td>78.90</td>
<td>0.11</td>
<td>0.70</td>
<td>2.20</td>
<td>17.00</td>
<td>1.30</td>
<td>1.20</td>
<td>50.00</td>
<td>21.00</td>
<td>4.90</td>
<td>0.01</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Source: EHNRI (1997)
Yewelsew et al. (2006) conducted a study to increase the energy density and vitamin A content of corn and kocho based infant foods by supplementing with legumes (kidney beans) and pumpkin pulps (Table 7).

The study had showed that, protein density (energy from protein as percentage of total energy) for legume-supplemented kocho, protein density was 14.9 % while the un-supplemented kocho was only 1.5 %. All amino acids were increased markedly by adding beans to kocho because kocho alone contained only 1.5 % protein. The retinol activity equivalent (RAE) is based on the assumption that 12 µg of dietary all-trans-β-carotene from food would be converted to the equivalent of 1 µg retinol while 24 µg of other dietary pro-vitamin A carotenoids would be required to form 1 µg retinol. Assuming that 50 % of the vitamin A activity contributed by pumpkin came from all-trans-β-carotene, and 50 % from other dietary pro-vitamin A carotenoids, the supplemented complementary foods both provided 54 µg RAE/100 kcal as fed.

Table 7. Nutrient density of the traditional and supplemented complementary foods as served

<table>
<thead>
<tr>
<th>Nutrient density</th>
<th>Legume supplemented Kocho (KBP)</th>
<th>Traditional Kocho(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy density (Kcal/g fresh)</td>
<td>0.46</td>
<td>0.49</td>
</tr>
<tr>
<td>Protein density (% of energy)</td>
<td>14.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Vitamin A density (µg RAE/100 Kcal)</td>
<td>54.4</td>
<td>0.3</td>
</tr>
</tbody>
</table>

*calculated values are based on chemical analysis for protein and vitamin A values and food table values for energy

*converted from total carotenoids (assumed to be 50% all-trans-β-carotene where 12 g = 1 g Retinol Activity Equivalent (RAE) and 50% other carotenoids where 24 g = 1 g RAE)

Source: Yewelsew et al. (2006)

The protein concentration of KBP (kocho: kidney bean: pumpkin supplement) was increased nine-fold over traditional kocho. The use of pumpkin improved the vitamin A density in KBP, compared with the un-supplemented kocho diet; the improvement in the vitamin A value was more than 180-fold in KBP. The addition of kidney beans enhanced the protein content of kocho-based complementary foods from 1.5 g/100 g (dry weight) 13.8 g/100 g. The pumpkin in KBP provided 54 µg RAE per 100 kcal, increasing the Vitamin A value of the mixes by 180-fold.

The addition of defatted soy flour at 5, 10, 15, 20 % to bulla flour gave acceptable product and significantly enhanced the quality and quantity of protein (Mulugeta T. personal communication).

**Using enset as industrial crop**

One of the main products of enset is bulla, which is in a very small quantity. Starch from enset is currently produced in a local factory owned by Yitbark and family business for textile and corrugated box factories. It can also be used in food processing.
Enset starch (Ensete ventricosum, Musaceae) has been examined for its chemical composition, amylase content and physico-chemical properties by Gebre-mariam and Schmidt (1996). The proximate composition of enset starch on dry weight basis was found to be 0.16 % ash, 0.25 % fat, 0.35 % protein, and 99.24% starch. The amylase content was 29%. Scanning electron microscopy (SEM) of enset starch granules showed characteristic morphology that was somewhat angular and elliptical. The starch has normal granule size distribution with a mean particle size of 46.8 m. Its moisture sorption pattern was similar to that of potato starch but much higher than maize starch. DSC parameters obtained from starch-water mixtures (1:2), namely, the enthalpy of gelatinization (AH: 21.6mj/mg), the onset temperature (T°: 61.8°C), the peak temperature (Tp: 65.2°C) and the end-set temperature (Tc: 71.7°C) were higher than those obtained for potato starch. Brabender viscosity curves of 6% starch paste showed lower peak viscosity (884 BU) than potato starch (1668 BU) but greater than maize starch (302 BU). The breakdown was also lower than potato starch but higher than maize starch. Retro-gradation of enset starch was substantially greater than potato starch but less than maize starch.

Challenges, Constraints and Gaps in:

Enset processing and utilization
Research activities have been conducted related to processing and nutritional improvements. However these research activities have not been enough to solve all the problems existed in processing and nutrition improvement aspects.

Fermentation, by virtue of microbial metabolic activities, contributes to the development of characteristic properties such as visual appearance, aroma, taste, texture, safety and shelf-life of a specific food product (Holzapfel, 1997). However, the outcome of uncontrolled spontaneous fermentation is not predictable and therefore variations in the quality and stability of the products could be of major importance. In a rather crude and empirical approach, inoculation of raw materials with a portion from previous batch ('back-slopping') of acceptable quality was experienced as a mixed starter culture to accelerate the traditional fermentation and improve predictability of the fermented product. Back-slopping is still used in many traditional food fermentations to control desirable changes that enhance predictability of the product. Thus, priority should be given to the development of appropriate starter cultures for use in kocho fermentation. The quality of starter culture used is one of the factors that determines the final quality and safety of fermented foods (Motarjemi, 2002). Therefore, searching of suitable microorganisms for development of starter cultures has become an issue to scale up the production of traditional fermented foods with enhanced predictability. Starter cultures are selected and used specifically for a substrate such as milk, meat, cereals, legumes, roots and tubers. Most commercial starter cultures originate from those food
substrates to which they are applied today. Utilization of starter cultures enables to exercise strict control of a fermentation process that results in a predictable product.

There is no well-developed and commercially available starter culture for fermentation of enset to produce kocho and bulla. Moreover, no protocols or methodologies are available to shorten the longer enset fermentation period thereby practice at industrial level. Therefore, modernization of fermentation process of enset and other Ethiopian traditional foods must be given due attention.

Enset products such as bulla and kocho are inferior on macro- and some micro-nutrient contents compared to other cereals and pulses. Moreover, micro-nutrient deficiency level in the enset growing areas is high compared to the other regions. Enrichment of these products with macro- and micro-nutrients are inevitable. Some research activities have been done to tackle these problems. However, research effort should be strengthen in number and quality thereby employ the research outputs to reduce and further eliminate the problems among the vulnerable group.

Using enset as industrial crop
Since the nineteenth century there is an enormous expansion in the starch industry, due largely to demands of the textile, color printing and paper industries, and to the discovery that starch can be readily converted into dextrin, which are gum-like product and other products. Starch is made mainly from maize, sorghum, wheat, potato, tapioca, rice, rye, oat, barley and others.

Currently, banana starch is certain to join the group of industrial starch source, because it can be obtained from culled bananas discarded by large banana plantations. Banana bunches are cut from trees in plantations and sent to a central processing station, where culs consisting of small or damaged fruit are removed. Such culs represent 25% of the banana crop and 25% of the green banana is starch. The starch can be readily recovered from banana pulp in a four-hour steep at an appropriate pH. Banana starch consists of large (20 μm) granules with properties suitable for a variety of applications. The production costs, essentially of cartage plus that of starch extraction, are expected to give a market price that approaches or equals that of corn starch.

However starch production particularly from enset in Ethiopia is meager. There is only one company that produces a certain amount starch from bulla. However, the company is refraining from producing starch from enset because of the ever increasing cost of bulla as raw material coupled with the expensive production cost of starch from enset. Users are importing from India and China, which is much cheaper than the locally produced product.
Recommendation

Although *enset* feeds over 20 percent of the population and is indigenous to the country, the attention given particularly on utilization, processing and opportunity as raw material for industry is very insignificant. In this case there are only few fragmented research achievements. Therefore, it is recommend that the following research and development areas be addressed to strengthen the few fragmented research achievements made so far

- There is no well-developed and commercially available starter culture for fermentation of *enset* to produce *kocho* and *bulla*. Protocols or methodologies that shorten the longer *enset* fermentation period thereby practicing at industrial level must be strengthened. Modernization of the fermentation process of *enset* and other traditional foods must be given due attention.
- Micro-nutrient deficiency level in the *enset* growing areas is high compared to the other regions. Food fortification and supplementation of *enset* food with nutrient rich foods must be developed. The bio-availability, bio-efficacy, other nutritional and functional properties of the enriched product should be studied.
- The already achieved research outputs, particularly in the area of food supplementation at the *enset* growing areas for vulnerable groups should be sensitized.
- *Enset* is a potential crop to produce starch for different industrial purposes. However, there is very little information available on characterization and processing of starch from *bulla*. As textile and other industries are growing fast, the need for starch as raw material is unprecedented. Therefore, there should an extensive research and development activities on the production of starch from locally and indigenous crops to facilitate and enhance import substitution for same.
- The presences of antibiotic-like substances in *kocho* and their inhibitory activity on gram-negative bacteria such as *Salmonella*, *Klebsiella* may have far reaching significance as in gastrointestinal tract microflora and infection. Hence, detailed studies on the chemicals produced by Lactic Acid Bactria during fermentation should be carried out.

Acknowledgments

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Gender Differentials in Enset Farming and Processing

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Abstract

This paper is a review of gender related information on participation of women and men in Enset production and processing at different parts of Ethiopia. The purpose of the paper is to reflect on the significance of understanding gender gaps in Enset research and utilization for addressing labor intensive problem and quality of Enset products. Literature reveals evidences on the close relation and responsibilities of women especially in post harvest management. Enset cloning, planting and replanting are done by men while harvesting and processing is done by women. Major processing methods include decortication, pulverization, fermentation, kneading and shredding. Enset is usually processed annually in most parts and usually by group of women through organizing shared or hired labor. Wooden and bamboo materials are used for kneading and shredding while large knife is used to cut leaves and the Enset plant. Culturally men are not allowed to enter to the processing area in most parts. Decision making in processing and marketing is done by women and income from sale of Enset is controlled by women. Women have sole responsibility of the harvesting and processing of Enset. Although attempts have been made for improvement of the post harvest management practices, the conventional methods are still dominantly used in the major Enset growing communities. Therefore, effective gender responsive research is further required on availing better decorticators, squeezers, processing devices and improved storage facilities that will reduce labor and improve quality of the produce. Strong multidisciplinary research projects should be designed to address gender gaps in reducing labor requirement and ensuring quality of the products.

Introduction

This paper constitutes findings reviewed from literature on the role of women and men in Enset production with special emphasis to the improvement of the post harvest management techniques that involves substantial time, labor, knowledge and special need. Observations related to post harvest management are highlighted to illustrate the existing challenges for further investigation and detailed research interventions.
The main objective is to indicate the relevance of considering gender gaps as development component and amend Enset research strategies towards solving problems related to productivity, quality and workload. Enset is one of the indigenous crops of Ethiopia and major staple food for nearly 20% of the population. Enset is widely grown in the Southern, Southwestern and central parts of the country. It is also a crop used for multiple purposes. It is used for food, feed, fiber, medicine and also considered as a sign of prestige (Endale, 1997). Literature indicates that Enset is known for its higher calcium content, carbohydrate, and iron content as compared to other root and tuber crops and even some cereals. (Kefale and Sariford, 1991). Enset food is prepared in various forms where many traditional dishes are prepared from it. It is a crop that can help to escape time of risk in food and feed deficit because of its good capacity to tolerate irregular rainfall patterns that may occur after the Enset plant is established. Currently, Enset starch is being used for textile, paper and adhesive industries (Ethiopian Science and Technology Commission, 2003).

Though Enset has enormous contribution to the food security, the progress in its improvement, particularly in post harvest and processing management is negligible and was not considered as high priority in technology generation.

Enset processing is constrained by cutting, grating, squeezing, chopping and storage. Attempts have been made on improvement of post harvest management through generating processing technologies/tools that can reduce labor, and improve quality of products. However, the conventional methods are still dominantly used in the major Enset growing farming communities.

The effort on improving processing tools was made by different stakeholders. The major ones include Agricultural Mechanization Department of the Melkasa Agricultural Research Center, Home science Department of the then Awasa College of Agriculture, now Hawasa University, the Sodo Rural Technology Development, and the Ministry of Agriculture. However, there was limited coordination effort in challenging the problem. Therefore, there is a need for implementing sound and effective coordination effort to look deep into what has been done in order to understand the system and the gaps and then to design better intervention mechanism.
Conventional processing methods of Enset

In Ethiopia, rural women play an important role in the agriculture sector both in farming and livestock production. Study conducted at different parts of the country indicates that women spend about 13 - 17 hours of a day in productive and domestic obligations. In some parts of the country like the pastoral and agro-pastoral areas women are also responsible for constructing mobile houses through collecting and preparing proper materials. Therefore, women have multiple roles and responsibilities in maintaining the wellbeing of their family through producing, processing and providing food for their family.

The tasks and responsibilities of women and men in various field of activity vary from location to location based on the cultural diversity, wealth status, education, and other related factors such as values and norms. Although there are variation in roles and responsibilities, women in Ethiopia are involved in seed selection and maintenance, land preparation, weeding, fertilizer and pesticide application harvesting, threshing and storing. The degree of involvement of women and men in each activity vary from location to location as mentioned above. Furthermore, like in many other developing countries, women are mainly responsible for food preparation and provisions such as pounding, grinding, fetching water and collecting fire wood. Child care and cleaning is also the responsibility of women and girls. In the farming activity, land preparation using animal power is done by men except in rare cases while other activities are shared among household members. With regard to livestock management, smaller animals are managed by women while men are responsible for larger ones. Utilization and or processing of milk and milk products (in small scale) is done by women.

In the case of Enset, cloning, planting and replanting are done by men while harvesting and processing is done by women. Culturally men are not allowed to enter harvesting area (Anita Spring, 1996; Judith and Helen, 1996). Enset is usually processed annually in most parts and usually done by group of women through organizing shared or hired labor. Decision making in processing, marketing, is done by women and income from sale of Enset is controlled by women. Liyuwork (1996) highlighted that Enset is processed by women farmers using wooden and bamboo materials and bigger size knife is used to cut leaves and the Enset plant. According to Liyuwork, the major processing methods include decortications, pulverization, fermentation, kneading and shredding. She also noted that the conventional Enset processing method is unsanitary and labor intensive and no adequate attempts were made to improve the situation.

Mehtzun and Yewlsee (1994) made detailed assessment of Enset processing methods and tools focusing on its improvement using gender perspective. They have indicated that Enset is widely cultivated and utilized in the Southern, Western and some central parts of the country. Lack of labor and time saving devices is one of
priority problems particularly for women farmers of Enset who depend on this crop as a source of food. Furthermore, Mehtzun and Yewelsew (1994) proposed to generate multipurpose technology that can be used for decorticating, pulverizing, squeezing, kneading and shredding. They looked at different attempts made by different institutes particularly the agricultural research centers in generating sound technology that provides simple adjustment to be easily accessed and become operated. This feedback was utilized by the research group but still there is a need for well organized and structured multidisciplinary effort for effective implementation. The conventional Enset processing devices are illustrated in (Figure 1, 2 & 3,) below. Enhancing productivity of the crop and such device will make effective contribution to reduce the problems related to food scarcity, productivity, quality, and generating better income.

Figure 1: Selecting and cutting matured Enset plant and making ready for processing
Figure 2: Decorticating Enset using conventional methods
Policies and strategies on enset research in EIAR

The Government of Federal Democratic Republic of Ethiopia shows strong commitment to support and strengthen gender-related activities at the national level. Public ministries, institutions and organizations are encouraged to have women’s affairs offices and to increase the representation of women in different forums. The
Government has given special focus to women’s contributions in social, economic, cultural and political affairs (Bogalech, 2000). The national constitution allows equal rights for women and men in all areas of social, political and economic development. Ethiopia has also accepted the global and African regional platforms for actions for the development of women. As part of the execution measures national endeavor, EIAR has also established gender research coordination office at head quarter level to coordinate the gender mainstreaming process in the National Agriculture Research System.

The current agricultural research system in Ethiopia, evolved through different course of actions that involve academic interest as well as participatory, problem-focused and policy-oriented. Different approaches have been utilized to make agricultural research more efficient and effective. These included package testing, farming systems approach, and participatory rural appraisal. Each route has played a significant role in sharpening the research focus towards being problem-oriented and demand-driven. Experiences indicate that farmers adopt improved technologies gradually depending on their priorities that are determined by their social, cultural and economic situation. Furthermore, the local problems and needs of farmers vary from location to location because of different local circumstances. Thus the farm survey results have helped researchers to understand the complexity of the system, to give due respect to farmers’ knowledge and to define research topics accordingly are important to consider. However, there was little room to consider gender aspect in the research process, particularly in the research planning process.

Several studies indicate that the role of women in agriculture has been overlooked and that this has contributed to the delay in the adoption of agricultural technologies (Chiche, 2002). Many global efforts are considering gender as an important component of development undertakings. In order to facilitate the consideration of gender in the research systems, it has to be internalized in the system and the organization’s staff needs to apply it in their daily activities. This could also be achieved by strengthening gender-responsive research in such a way that it can adequately addresses the interests of all women and men farmers who are responsible for maintaining livelihoods through farming. In this regard, The Ethiopian Institute of Agricultural Research has developed gender mainstreaming strategy that will enable researchers to consider gender factors in different research activities. Gender considerations can facilitate the understanding of allocation and utilization of available resources and benefits, identifying vulnerable groups and their coping mechanisms and hence develop policies that would enhance interventions for specific projects. Therefore, rigorous gender research is essential to supplement development policies for effective and productive action.
Conclusion

- Enset is widely grown in Southern and Western parts of Ethiopia, and is used for a wide range of purposes, food, feed, medicine and source of income.
- Clear division of labor by women and men are observed in Enset production.
- In almost all Enset growing areas, women are responsible for harvesting and post harvest management activities while men are more involved in the planting and maintenance.
- Culture and norms have restricted men not to assist in processing.
- Conventional processing methods of harvesting and planting are widely practiced by women farmers.
- Facilities of the conventional methods the pits and processing are not hygienic and it is time consuming and labor intensive.
- The product still needs further post harvest management research to improve the productivity and nutritional quality.
- The national and institutional policies are conducive to conduct gender focused research activities. However, there seems to be still a gap on how to harmonize the long lived experience with the new approach of using gender perspective in technology planning.
- Capacity development for research technicians is important to enable them to use gender perspective and thereby gender responsive projects could be developed and implemented towards Enset processing and utilization.
- Demonstration of improved processing devices have been developed but not widely disseminated.
- Efforts of Interventions made so far should be replicated, widely disseminated and scaled out.
- Strong multidisciplinary research projects should be developed to generate better processing and preservation methods for the subsequent and sustainable implementation that improves the quality and food values of the products. Hence, research should give a special attention and focus for larger scale of impact through establishing task forces that would gain from similar activities.

Recommendations

Enset has been a preferred staple food for almost 20% of the Ethiopian population. Yet, Enset has multipurpose uses than many other different crops. Despite its demanding nature for harvesting and processing, Enset can easily be used as crop of food security where women have sole responsibility of the harvesting and post harvest management activities. However, research in the post harvest management didn't make significant impact in terms of labor and time saving as well in enhancing the quality of the product. One of the approaches in improving food quality is through application of better pre and post harvest management techniques which are essential to addressing problems related to food insecurity. Hence, improving food availability, utilization and nutrition through better pre and post harvest technologies is indispensable. Therefore, support from the research institutes in
consideration the pre and post harvest management practice/activities is vital in addressing the problems associated with food insecurity and poverty.

Therefore, research intervention is required to consider the challenges of both women and men to address major constraints of the community at large and also to target the disadvantaged group of society (women) in particular. Introduction of decorticators, squeezers, processing devices in particular and storage facilities that will reduce labor and improve quality of the produce would have positive implication on sustainability of the production. Processing devices should be considered as one of the parameters in Enset improvement related activities.

In conclusion, detailed study of market oriented Enset food production methods that focus on food quality and nutritional values need to be further developed. Finally, this paper attempts to bring on board the relevance of gender element and its consideration in the research design focusing on major challenges and constraints to availing Enset food products. Previous studies on post harvest management of Enset had identified factors that are important in Enset processing and management. Future research endeavor should be based on past achievements as springboard for post harvest problem identification and looking for alternative mechanism for improvement.

References


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