CURRENT RESEARCH TRENDS, GAPS AND FUTURE DIRECTION FOR A COORDINATED MULTIDISCIPLINARY APPROACH

International Workshop on enset (Ensete ventricosum) for Sustainable Development, Oct. 17—18, 2016, Addis Ababa, Ethiopia
Enset for Sustainable Development

CURRENT RESEARCH TRENDS, GAPS AND FUTURE DIRECTION FOR A COORDINATED MULTIDISCIPLINARY APPROACH


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International Workshop on enset (Ensete ventricosum) for Sustainable Development, Oct. 17—18, 2016, Addis Ababa University, Addis Ababa, Ethiopia

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International Workshop on enset (Ensete ventricosum) for Sustainable Development, Oct. 17—18, 2016, Addis Ababa University, Addis Ababa, Ethiopia
## Workshop Program

<table>
<thead>
<tr>
<th>Activity/Chair/Rapporteur</th>
<th>Time</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>17 Oct 2016</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Registration</td>
<td>08:30 - 09:00</td>
<td>Organizers</td>
</tr>
<tr>
<td>Programme Introduction</td>
<td>9:00 – 9:10</td>
<td>Dr. Tamirat Bekele. Head DPBBM /Prof. Zerihun Woldu, Director of Research, AAU</td>
</tr>
<tr>
<td>Prof. Zerihun Woldu, Director of Research, AAU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Welcoming address</td>
<td>09:10 - 09:20</td>
<td>Dr. Admassu Tsegaye, AAU President</td>
</tr>
<tr>
<td>Opening Remark</td>
<td>09:20 - 09:30</td>
<td>Guest of Honour</td>
</tr>
<tr>
<td>Objectives of the International Workshop on enset (Ensete ventricosum) and expectations</td>
<td>09:30 - 09:50</td>
<td>Prof. Sebsebe Demissew, AAU</td>
</tr>
<tr>
<td>Current trends and gaps in enset research</td>
<td>09:50 – 10:10</td>
<td>Prof. Masresha Fetene and Getahun Yemata</td>
</tr>
<tr>
<td>What collections-based research is needed to determine climate-smart crops of the future?</td>
<td>10:10 – 10:30</td>
<td>Prof. Katherine J. Willis, KEW</td>
</tr>
<tr>
<td>Coffee Break</td>
<td>10:30 - 11:00</td>
<td>Organizers</td>
</tr>
</tbody>
</table>

**Thematic Presentations**

**1. Genetics and Industrial products**

Prof. Kathy Willis, Director of Research, Kew, UK/Paul Wilkin

<table>
<thead>
<tr>
<th>The genome and genomics of Enset: what can we learn from banana and other crops to enable Enset to reach its potential?</th>
<th>11:00 - 11:15</th>
<th>Prof. Pat Heslop Harisson</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Center of origin and domestication of Ensete ventricosum and its phylogenetic relationship to some Musa species</td>
<td>11:15-11:30</td>
<td>Prof. Endashsaw Bekele</td>
</tr>
<tr>
<td>Industrial uses of enset: application in the food, animal feed, paper, textile and brewery industries</td>
<td>11:30 - 11:45</td>
<td>Dr. Amare Gessese</td>
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<td>Industrial applications of enset starch and its modifications: from native starch to nanoparticles</td>
<td>11:45 - 12:00</td>
<td>Prof. Tsige G. Mariam</td>
</tr>
<tr>
<td>Applications of Biotechnology to Improve the Productivity of Ethiopian Orphan Crops: Enset, Ethiopian Traditional Tuber</td>
<td>12:00 – 12:15</td>
<td>Kassahun Tesfaye, Zerihun Yemataw, Amare Gessesse</td>
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<tr>
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<tr>
<td>Discussion</td>
<td>12:15 - 13:00</td>
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</tr>
<tr>
<td>Lunch</td>
<td>13:00 – 14:00</td>
<td>Organizers</td>
</tr>
</tbody>
</table>

### 2. Physiology and Pathology

Prof. Masresha Fetene, Executive Director of EAS, Dr. Mekuria Tadesse

| Challenges, research status and strategy for enset (Ensete ventricosum (Welw.) Cheesman) research and development in Ethiopia | 14:00 - 14:15 | Sadik Muzemil, Zerihun Yemataw and Eshetu Derso |
| Improving indigenous knowledge of propagation for the development of enset agriculture: promoting farmers’ adaptation capacity to climate change | 14:15 – 14:30 | Prof. Karlsson LM, Dalbato AL and Tamado,T. |
| Relevant research questions on the crop physiology of enset | 14:30-14:45 | Prof. dr.ir Paul Struik |
| Status of Research on Enset Diseases and its Management | 14:45 – 15:00 | Dr. Adane Abraham |
| Enset bacterial wilt (EBW): Towards an integrated management strategy | 15:00 – 15:15 | Getahun Yemata, Masresha Fetene, Bruktawit Desta and Tesfaye Alemu |
| Endophytes of enset: potential applications for the control of bacterial wilt disease and as plant growth-promoting agents | 15:15 – 15:30 | Dr. Yemisrach Mulugetta |
| Discussion | 15:30 - 15:45 | |
| Coffee Break | 15:45 - 16:00 | Organizers |

### 3. Land use, Agronomy, Nutrition and Food products

Prof. dr.ir. Paul Struik, Centre for Crop Systems Analysis, Department of Plant Sciences, Wageningen University and Research Netherlands/ Prof. Sileshi Nemomissa, AAU
| Land use changes in the Enset-based agroforestry systems of Sidama, Southern Ethiopia and its implications to agricultural sustainability | 16:00 -16:15 | Dr. Tesfaye Abebe |
| Agronomy and biodiversity of enset | 16:15 – 16:30 | Dr. Admassu Tsegaye |
| The diversity, challenges and management of enset (Ensete ventricosum (welw.) Cheesman) by the Kembatta people, Southern Ethiopia. | 16:30 – 16:45 | Melesse Maryo, Sileshi Nemomissa and Tamrat Bekele |
| Nutritional Profile of Enset based Food Products: Current Knowledge, Research Gaps and Future Directions to Exploit its Nutritional and Health Benefits | 16:45 - 17:00 | Dr. Ashagrie Zewdu |
| Biotechnological studies and Yeasts and bacteria associated with kocho, an Ethiopian fermented food from Ensete ventricosum | 17:00 – 17:15 | Dr. Genet Birmeta |
| Discussion | 17:15 - 17:40 | |
| Cocktail | 18:30 - 20:00 | |

**18 Oct 2016**

**4. Ethnology and Ethnobotany**

Dr Gemedo Dalle  
Dr Tesfaye Awas, Ethiopian Biodiversity Institute

<p>| The Enset Field Gene Bank Initiative: A viable option to conserve the invaluable tuber crop sustaining millions of households | 9:00 – 9:15 | Dr. Feleke Woldeyes |
| ENSET (Ensete ventricosum) Ethnobotany: Research Trends, Gaps and Hints to Forward Steps | 9:15 – 9:30 | Prof. Zemede Asfaw |
| Initiatives on Enset research together with the grassroots - In order to sustain and develop the assets for the coming generation | 9:30 – 9:45 | Dr. Asnakech Woldeten-saye |
| Changes and development of Ensete landrace diversities in South Omo: Observation of indigenous agricultural activities for the last 30 years | 09:45 - 10:00 | Prof. Masayoshi Shigeta |
| Farmers View of enset research (Woman) | 10:00 – 10:15 | |
| Farmers View of enset research (Man) | 10:15 – 10:30 | |
| Coffee break | 10:30 - 10:50 | Organizers |
| Discussion | 10:50 - 11:20 | |</p>
<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
<th>Organizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel Discussion</td>
<td>11:20-12:20</td>
<td>Ministry of Agriculture, Ministry of Science and Technology, SNNPRS, Ethiopian Institute of Agricultural Research, Ethiopian Biodiversity Institute</td>
</tr>
<tr>
<td>Mr. Asrat Bulbula, Ex-Commissioner of Ethiopian Science and Technology Commission</td>
<td>11:20-12:20</td>
<td>Ministry of Agriculture, Ministry of Science and Technology, SNNPRS, Ethiopian Institute of Agricultural Research, Ethiopian Biodiversity Institute</td>
</tr>
<tr>
<td>Discussion</td>
<td>11:20–12:40</td>
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<tr>
<td>Synthesis of the Workshop</td>
<td>12:40–12:55</td>
<td>Dr. Feleke Woldeyes,</td>
</tr>
<tr>
<td>Declaration</td>
<td>12:55 - 13:00</td>
<td></td>
</tr>
<tr>
<td>Lunch</td>
<td>13:00 – 14:00</td>
<td>Organizers</td>
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<tr>
<td><strong>19-21 Oct. 2016</strong></td>
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Objectives of the International Workshop on enset (Ensete ventricosum) and expectations

Sebsebe Demissew
National Herbarium, Department of Plant Biology and Biodiversity Management, College of Natural Sciences,
P.O. Box 3434, Addis Ababa Ethiopia:
e-mail: sebseb.demissew@gmail.com

Extended summary
The objectives of the International Workshop on “Enset (Ensete ventricosum) for Sustainable Development: Current research trends, gaps and future direction for a coordinated multidisciplinary approach in Ethiopia” is to bring together researchers from both the natural and social sciences in order to capture the wealth of vital information from various research areas carried out in the past four to five decades, identify the research gaps in their areas of expertise and reach a consensus on these. On the way forward, a multidisciplinary approach for Enset Research, a realization of science-policy platform for enset research and identification of a centre of excellence for enset research and its sustainable use will be discussed.

Key words: Enset (Ensete ventricosum), Research, Science-policy

Introduction
Enset (Ensete ventricosum) is a multipurpose crop providing a range of services such as food, forage, medicine, ritual, construction and soil protection. The different uses are attributed to the existence of different enset varieties (YemaneTsehaye and Fassil Kebebew, 2006). Enset is distributed in the wild throughout much of central, eastern and southern Africa. However, it is known to have been cultivated (Simmonds, 1958; Taye Bizuneh et al. 1967), domesticated (Brandt, 1996) and the farming system established in Ethiopia (Ehret, 1979). Currently about one-fifth of the Ethiopian population (20 million) depend on this crop mainly in the southern region and adjoining places in Oromiya and Gambella Regions.

Despite the important attributes such as the harvest of the crop throughout the year, storage over a long period, high yield per unit area and the enset system having a high human carrying capacity compared to cereal growing regions, the enset agriculture was deprived of the research attention it deserved compared to cereal agriculture.

History and Research, and Gaps
There has been documentation on the history and cultural aspects of enset (both wild and cultivated), and its distribution by many scholars as presented by Blench (2007).

The social science components (farming systems, enset land races, indigenous knowledge and practices) and natural science components (including Agronomy, Genetics, Morphology, Taxonomy, Bacterial Wilt) have been carried out over the last 40 years or more. The research that has
been going on mainly in natural science disciplines have been carried out largely in isolation. Research areas with inadequate information are also identified.

**Science-Policy Interface**

One of the major problems in Ethiopia and elsewhere in developing countries is the lack of communication between researchers and policy makers and hence the direct impact of research results on policy is rare and far in between. Thus there is a need to work a mechanism to have a workable science-policy interface. According to Watson, Chair of the International Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES (personal communication), “informed policy formulation, whether at the national, regional or global scale, requires state-of-the-art credible multi-disciplinary knowledge that recognizes the needs of society, decision-makers, the political context of decision-making, and that inter- and intra-generational equity issues are critically important”.

**Expectations**

The expectations from this international enset workshop that brings researchers from both the social and sciences, and policy makers are: to reach a common understanding/consensus that a multidisciplinary approach is the only way forward to develop a sustainable future for enset, system and the livelihood of communities depending on it; working towards a science-policy interface where research results influence policy through effective communication; policy makers to use research results to make informed decisions in promoting enset as one of the important indigenous crops and to take steps to recognize/identify a Centre of Excellence on Enset in Eastern Africa in general and in Ethiopia in particular in a similar way as there is Centre of Excellence on Yam Research in West Africa.

**References**


Current research trends and gaps in enset agriculture

Masresha Fetene¹ and Getahun Yemata²
¹Addis Ababa University, Department of Plant Biology and Biodiversity Management ²Bahir Dar University, Department of Biology

Extended summary

Enset is a multipurpose traditional crop widely cultivated in south and southwestern Ethiopia. It feeds approximately 20 million people in the country. The crop has a number of desirable qualities which makes it superior over other crops and preferable in a population facing food insecurity. For instance, enset gives the highest yield per unit area and thus supporting the densely populated areas in the country. Enset foods can be stored for long periods. The crop performs better than other crops even without the use of costly agricultural inputs. Furthermore, although the crop has long maturity time, it is possible to harvest, before it attains maturity, allowing enset growers to surmount periods of food shortage. Despite these qualities, the crop has received not much research attention as compared to cereals.

Enset research started in the 1970s when clone characterization and selection for agronomic traits was the main focus. Since then, research activities progressively increased in magnitude addressing the different aspects of the crop coming up with important findings. Despite the large variation in agroecological conditions among enset growing areas, molecular studies reveal that only 4.8 % of the total genetic variation is found between zones and 95.2 % within zones or populations. Thus, the cultural, social and economic basis of this variation, as well as advantages and disadvantages of the different traditional practices of each ethnic group need to be investigated.

Some findings reveal that enset clones differ in performance when grown under different environments, for example, altitudinal variation. In order to recommend clones to specific environments, there is need to study growth requirements and yield determining factors for the different agro-ecologies and screen out promising clones for specific environments. According to ecophysiological studies, drought tolerance in enset is found to be due to osmotic adjustment and improved water extraction through altered biomass partitioning. However, due to the high enset clonal diversity, many more screening studies to search for more physiological traits that confer tolerance to low moisture stress and understand whole plant water use efficiency remain to be done. Moreover, studies showing the interactive effects of multiple environmental factors on the growth and yield of enset are absent. The enset-production system involves intercropping with diverse crop species as well as landrace mixtures. To advance the production system and increase productivity per unit area, researches on more compatible crops for intercropping, the nursing effect of enset and the best mixtures of enset landraces should be conducted.

In enset farming, productivity can be sustained by implementing management practices that reduce nutrient loss from the system and cultivation of clones with higher nutrient use efficiency. Nonetheless, farmers pile the animal dung and other household refuse between enset plants in...
manure for 3-4 months before transplanting of enset suckers. This according to research reports causes substantial loss of nitrogen and carbon that in turn alter C: N ratio. A research on the net rate of manure mineralization indicated highest values at early periods of incubation and slowing at later periods. Therefore, application of manure close to transplanting and immediate incorporation into the soil is recommended. Since the rate of mineralization depends on climate, soil and the enset clone, and the result belongs to a specific area, similar studies should be done in other areas. There is also no information about the nutrient use efficiency of enset clones and thus screening studies are required.

Industrially, the starch that can be used for paper, textile and adhesive industries is produced from enset. There are good beginnings to see the potential use of enset starch in tablet formulation as a binder and disintegrant. Research reports also show the potential use of Bulla (dehydrated juice of processed enset parts) as a gelling agent in in vitro plant micropropagation substituting agar. However, more remains to be done to exploit the large starch (60%) content of the crop industrially.

Enset is a crop that can easily reproduce by vegetative propagation. More to the point, tissue culture as a biotechnological tool has been tested and found to be effective in enset propagation. Research results have shown that micropropagation of enset shoot tip culture rapidly produces large numbers of clonal plantlets that are free of pathogens. In spite of the findings, many more studies should be conducted about optimization of the protocol and hardening of the plantlets under glasshouse and field conditions. The tool would also be used to propagate new genotypes and/or specific pathogen tolerant clones.

The use of genetic engineering as an important tool to efficiently deliver genes carrying desirable traits from another species to enset so as to develop tolerance in enset to different environmental factors including enset bacterial wilt needs to be explored.

Of all environmental factors, enset bacterial wilt (EBW) caused by Xanthomonas campestris pv. musacearum (Xcm) is the most important constraint to enset cultivation. The pathogen also affects banana. Once established, the disease is difficult to control owing to the lack of an effective chemical or other curative treatment. Currently, researchers suggest using phytosanitary approaches that involve the destruction of diseased plants as the only option to control the disease. Although there are early developments to find alternative methods of controlling the disease, most previous studies were focused on characterization of the pathogen and assessing enset clones resistance against Xcm. The most attractive strategy for bacterial disease control in crops is to improve their natural defense mechanisms against a pathogen. Related to this, research results have shown that induction of resistance can reduce disease incidence by 20-80%. Inducing plants of a susceptible clone by the crude leaf extract of a medicinal plant reduced disease incidence in enset by 33% showing the potential of the technique to control the disease. However, several researches need to be carried out on screening of medicinal plant extracts, evaluation of application methods and integrated management strategies. Moreover, the role of other biocontrol agents such as arbuscular mycorrhizal and Trichodermal fungi should also be evaluated. In banana, researchers were able to produce bacterial wilt resistant banana varieties using transgenes encoding for plant ferredoxin-like protein (pflp) and hypersensitive response assisting protein (hrap) isolated from sweet pepper (Capsicum annum).
These are novel plant proteins that can intensify pathogen mediated hypersensitive response. Since the pathogen is the same, genetic engineering studies to develop enset clones resistant to Xcm should be conducted at a large scale.

Generally, despite the relatively better research attention given to enset in the past decade as compared to the previous decades, there are still several research gaps that need to be addressed using coordinated multidisciplinary approaches.
What collections-based research is needed to determine climate-smart crops of the future?

Prof. Kathy Willis, Director of Science, Royal Botanic Gardens, Kew, Richmond, Surrey, TW9 3EA, UK; E-mail: k.willis@kew.org

Summary

It is widely acknowledged that the Ethiopian crop enset has the potential to be a climate-smart crop of the future. As a crop, it currently provides a food source for ~20 million people in Ethiopia via its corm and stem base supplying dietary starch. It also supplies fibres, medicines, and animal food. In addition, enset is important for the ecosystem services that it provides; it is a key food source for bees, stabilises soils and it is culturally significant. More critically, however, it has the ability to withstand long periods of drought. On the face of it, therefore, enset appears to be an excellent plant to promote when planning for food security and supply in Ethiopia in the face of future climate change, pest and pathogen outbreaks.

However, there are a number of candidates for ‘climate-smart’ crops of the future in Africa and in order to compare and contrast the potential of enset against these other crops, there are a number of critical knowledge gaps that need to be addressed. These include questions around its ecology, genetic diversity, flowering and fruiting biology, and the ability of different varieties to withstand pest and pathogens. This broad array of knowledge gaps require a multi-disciplinary approach and a scientific evidence base that moves beyond models but instead uses collection-based research backed up by in situ field-based studies.

The Royal Botanic Gardens, Kew (RBGK) has one of the world’s largest plant and fungal collections-based research facilities. It has 257 years of working with partners all over the world to document and understand global plant and fungal diversity and its uses in order to bring robust scientific evidence to address some of the most critical challenges facing humanity today. This talk will illustrate with past and on-going research programmes at Kew, how this multi-disciplinary and multi-partnered approach has been used to fill critical knowledge gaps for plant and fungal groups that provide important societal benefits to mankind. It will then introduce the proposed work on enset to be undertaken in the new collaboration between RBGK, University of Leicester and Addis Ababa University; research that aims to determine the potential of Enset to maintain provide a resilient food supply in Ethiopia for the future.
The genome and genomics of Enset: what can we learn from banana and other crops to enable Enset to reach its potential?

Pat Heslop-Harrison, phh@molcyt.com
www.molcyt.com
University of Leicester, UK

Summary

Studies of the DNA of many major crop species are advancing their breeding and production. Genomics is enabling improved methods, giving better accuracy and faster selection of new varieties, by exploiting the biodiversity in the germplasm of crops and wild relatives, generating new sustainable genotypes with characteristics such as disease resistance, yield, and water usage. About half of the increase in crop yields in the last 40 years can be attributed to genetic improvement, while the other half comes from improvements in agronomy. The study of DNA sequences tells us about all the genes which are present, and the evolutionary history of a species group. It measures the diversity present. With genome mapping, marker assisted selection (MAS) is possible, to find lines with optimum characters for yield or for adaptation to the environment. This work enables aspects of breeding to be shortcut, and the characteristics can be brought together in new varieties using a range of hybridization and genome editing approaches – with targeted approaches which can be regarded as superdomestication (Vaughan et al. 2007).

Plant breeders can work with large amounts of DNA sequence information including the sequences of all genes and the repetitive DNA that makes up the majority of most genomes. Knowledge of the diversity and evolution of the sequences is proving important to developing DNA markers, identifying genetic and QTL characters, the selection of breeding lines and the measurement and exploitation of biodiversity in combination with morphological markers (see, e.g. Worku et al. 2015 for an example). Nuclear DNA sequence information can be used for improvement all crop species with directed superdomestication approaches leading to improved performance, resistances to biotic and abiotic stress, and greater environmental sustainability to meet the challenges of increasing populations and climate change. Genome studies enable the history of crop domestication to be examined. Major crops have been through millennia of selection from their wild relatives. (See Heslop-Harrison, 2017, for expansion of this paragraph.) In banana (Musa species, and including the plantains as well as desert and cooking bananas; Heslop-Harrison and Schwarzacher 2007), we were part of the project sequencing the genome (D’Hont et al., 2012). Understanding the genes of more species may enable selection of desirable genotypes of currently unused or underutilized species, and the improvement of other crops so they can be farmed in more sustainable ways.

Enset has not had the amount of work on the genome and genomics of other crops of similar regional importance. However, the techniques and approaches based on understanding genome organization (Heslop-Harrison and Schwarzacher, 2011) and genomics are widely...
applicable and we can now exploit information about plant nuclear genomes in breeding of all species. The potential for predictability and systematic design of requirements from crops – superdomestication – using genomic information and molecular breeding is enabling the acceleration of crop improvement to meet the requirements of increasing populations, climate change and environmental sustainability. Internationally, the importance of technological solutions and genetics for agriculture is increasingly recognized (eg in the European Parliament, McIntyre 2016). In this talk, I will discuss further what we know and how this information can help increase the exploitability of enset in a sustainable manner with changing demands on the crop from people and the environment.

References


Further information is on my website www.molcyt.com
The Center of Origin and Domestication of Ensete ventricosum (Welw.) Cheesman and its phylogenetic relationship to Some Musa Species.

Prof. Endashaw Bekele, Department of microbial, cellular and molecular biology, College of Natural Sciences, AAU.

Summary

Published reports on research activities of Ensete ventricosum are highlighted. The species composition of Genus Ensete is still unsettled. The distributions of the various currently recognized species of the genus in Africa and Asia are given. A gap that exists on a systematic account of its origin and domestication is partially filled and needs further research. One of the reasons for the disputes on the center of origin in literature is partly due to unclear demarcation between the concepts of species centre of origin and center of initial domestication of a given species. To trace the origin of domesticated enset and early food production in Ethiopia historical evidence and historical accounts of its distributions, botanical differences between cultivated and wild ensete forms and magnitude of accumulated genetic diversity over several thousands of years, climatic period changes based evidences and evidence from livestock interactions are cited and commented on.

Based on Ecological distribution of wild Ensete ventricosum in Ethiopia, the highly dissected terrain of lower altitudes of South and South Western drier zones of Ethiopia might be the initial sites of enset domestication. The complexity of enset culture and its use value in South and South West of Ethiopia indicate longer period of enset cultivation. The existence of dynamic subsistence enset and other tuber crops as well as the fact that agriculture based on roots and tubers preceded that based on seeds and fruits also support the early domestication of enset in South and South West of Ethiopia.

A molecular genetic data from RAPD and ITS DNA sequence suggest that different clones of cultivated enset seem to have originated from different clones of wild Ensete ventricosum suggesting the existence of several microcenters of domestication in the region. Both RAPD and ITS data clearly demarcate the eight Musa species and cultivated and wild enset forms studied. The wild Ensete ventricosum and the cultivated forms seem to introgress and escape to the wild and domesticated sites of ensete, respectively.

Complete sequences of transcribed spacers and introns from trnT trnF region of chloroplast DNA from thirteen species of Musa and three species of Ensete including the cultivated and wild species of Ensete ventricosum revealed that Musa beccarii represent ancestral forms of ensete and Musa, Ensete gilleti or a species very close to it appears to be the ancestral species of E. ventricosum.

Key words: Ensete ventricosum, Musa species, molecular data, phylogeny, Centre of origin and domestication
Industrial uses of enset: application in the food, animal feed, paper, textile, and brewery industries

Amare Gessesse: Institute of Biotechnology and Department of microbial, Cellular, and Molecular Biology, Addis Ababa University, Addis Ababa, Ethiopia, Tel: +251-945973703; e-mail: amare.gessesse@gmail.com amare.gessesse@aau.edu.et

Summary

Enset is a multipurpose crop with a wide range of industrial and food applications. However, to date, the use of enset has been restricted to its traditional food use, mainly in the form of kocho and bulla. But enset has a huge potential for the production of a variety of industrial products. To do this, it is important to develop appropriate processing techniques.

Almost all crops that are currently under cultivation in the world are single use crops where only one part of the plant (the seed, tuber, stem, or leaves) is used as a source of food or industrial product. The rest of the crop is released as agro-industrial waste with limited or no use. But enset is a unique crop where all parts of the plant are used for different applications. The underground corm, together with the scraps of the pseudostem, is traditionally used for the production of kocho and bulla. By employing appropriate processing techniques the corm gives high quality starch and animal feed. The pseudostem is also used for the production of starch and high quality fiber. The leaf and the pseudostem give high quality fiber for different applications.

By employing appropriate enzymatic and chemical processing techniques, enset starch finds important applications in different industrial processes. These include as adjunct in breweries, warp sizing in textile industries, paper sizing in the paper and pulp industry, and for pharmaceutical uses. After enzymatic hydrolysis, enset starch is converted to glucose, maltose, or other syrups for use in food industries, confectionary industry, or pharmaceutical industries.

The second most important product generated from enset is high quality fiber that can be used for the production of specialty papers, such as currency notes, tea bags, etc. that require the use of long and high strength fibers. Enset fiber can also be used for the production of high quality papers and packaging or to supplement short and inferior fibers in the pulp and paper industry. While processing different parts of enset for starch, food, and fiber, huge quantity of feed is generated that can be used for different animals.

Despite the importance of enset as a multipurpose industrial crop, to date traditionally processing has been the biggest bottleneck for its wide application. Recently a method for industrial scale processing was proposed, the main features of which will be discussed in this presentation.
Industrial applications of enset starch and its modifications: from native starch to nanoparticles

Tsige Gebre-Mariam, School of Pharmacy, Department of Pharmaceutics and Social Pharmacy, College of Health Sciences, AAU, tsige.gmariam@aau.edu.et

Extended summary

Starch is the most extensively utilized biopolymer that has different industrial applications. It is used as a component and/or processing aid in the manufacture of products such as food, pharmaceuticals, textile, paper, and adhesives. This is a summary of the work done by our research group over the past two decades on various starches obtained from plants grown in Ethiopia.

Characterization and evaluation of native starches - The plant enset is cultivated as a source of food (kocho and boulla) in south and south-west Ethiopia. The proximate composition of enset starch extracted from boulla on dry weight basis was found to be 0.16% ash, 0.25% fat, 0.35% protein, and 99.24% starch. The amylose content was 29%. Scanning electron microscopy of enset starch granules showed characteristic morphology that was somewhat angular and elliptical. Enset starch has normal granule size distribution with a mean particle size of 46 µm [1]. Evaluated as a binder and disintegrant in compressed tablets, enset starch was found to compare favorably with potato and maize starches and can be used both as a tablet binder and disintegrant [2].

Modified starches - Starch continues to be attractive as a material of choice not only because of its availability and low cost but also due to biodegradability, environmentally benign properties and ease of chemical modification. However, due to its limitations such as its poor compressibility, flow property, and limited swelling capacity, native starch is often modified, which renders wide applications as binder, filler, emulsion stabilizer, consistency modifier and adhesive.

Super-disintegrant sodium enset starch glycolate - Enset starch was modified into sodium starch glycolate and evaluated as a super-disintegrant in compressed tablets (sodium starch glycolate is the sodium salt of a carboxymethyl ether of starch). Sodium starch glycolate of enset starch was found to be at least as efficient as marketed sodium starch glycolate - Primojel® or Croscarmellose sodium, NF- Ac-Di-Sol®. In soluble tablet formulations, sodium starch glycolate of enset was more efficient than Primojel® or Ac-Di-Sol®. Tablets prepared with sodium starch glycolate of enset exhibited shorter disintegration times, faster rates of swelling and water uptake. In insoluble tablets, however, significant differences were not found in the efficiency of the sodium starch glycolates [3].

Sustained release enset starch - Enset starch was cross-linked in solid phase system in a microwave under different powers and reaction times, using a cross-linking agent. The cross-linked starches were investigated for their drug-release-sustaining ability. Depending on the degree of
cross-linking, the modified enset starch microspheres showed different drug loading capacities. Tablet matrices containing cross-linked enset starch sustained the release of the model drug over a period of 24 hrs implying the potential use of cross-linked enset starch as drug-release-sustaining pharmaceutical excipient [4].

Pregelatinized enset starch- To improve its flowability and compaction enset starch was modified by a physical method called pregelatinization. In a comparative tablet formulation study, pregelatinized enset starch showed improved flowability, compressibility, and enhanced swelling capacity than the native starch and the overall performance of pregelatinized enset starch was comparable to Starch 1500® [5].

Acetylated enset starch- In an effort to produce directly compressible matrix former, enset starch was chemically modified by acetylation with different degrees of substitution. Studies on physical properties indicated acetylation improved the flow property of the modified enset starch. Drug release studies from matrix tablets revealed rate of release changed from rapid release to sustained release as the degree of substitution increased. Dissolution studies showed that enset starch acetates with high degree of substitution could act as matrix-forming agents in tablets, where the release of a drug can be significantly sustained [6].

Suspending and gelling enset starch- Enset starch was carboxymethylated for application in topical drug delivery of antinflammatory drugs. Formulations were evaluated and optimized in terms of cosmetic qualities, gel clarity, spreadability, homogeneity, and extrudability. In a comparative study, using model drug and appropriate concentrations of the gelling agents, and synthetic cellulose acetate membrane as well as model animals, it was possible to deliver both in vitro and in vivo the required amount of the antinflammatory drugs. The medicated gels showed excellent stability profile under optimum storage conditions [7].

Nanoparticles of enset starch- Enset starch nanoparticles with particle size less than 200 nm and PDI below 0.2 were fabricated using emulsion solvent diffusion and evaporation method. Nanoparticles containing ibuprofen as a model drug were formulated and studied for their encapsulation efficiency, in vitro drug release as well as stability. In vitro release profile of the nanoparticles at 37 °C demonstrated that drug release was controlled well over a period of 8 hrs. Furthermore, the optimized nanoparticles were found to be stable over three months of stability studies. The results suggest that enset nanoparticles can be used as nano-carriers for the encapsulation and sustained release of hydrophobic drugs [8].

Native and modified enset starches are depicted in Fig.1.
Fig. 1: Native enset starch and its modifications

References


Applications of Biotechnology to Improve the Productivity of Ethiopian Orphan Crops: Enset, Ethiopian Traditional Tuber

Kassahun Tesfaye¹,³ Zerihun Yemataw², Amare Gessesse³

¹Ethiopian Biotechnology Institute, Ministry of Science & Technology, Addis Ababa
   (kassahuntesfaye@yahoo.com)
²South Agricultural Research Institute, Hawassa (yemataw.zerihun@yahoo.com)
³Institute of Biotechnology, Addis Ababa University, Addis Ababa (amare.gessesse@gmail.com)

Summary: Enset is native to Ethiopia and has been cultivated for several decades as a food crop. In addition to food values, enset is also used as a medicinal plant, animal feed, and rope for home and fence construction. The natural tolerance of orphan crops including enset allows them to continue growing in harsh environments, through inherent traits such as drought tolerance to ensure productivity under changing climate. However, they are often forgotten in international R & D programs, although they could have potential to contribute to sustainable food security. Recent advances in genomics and methods in biotechnology have resulted in better understanding of the interaction of genetic and environment for plant development and plant performance. In line with this, few attempts have been made by NARS in Ethiopia and international partners to apply biotechnological approaches and genomics tools for enset conservation and improvement.

The genetic variability of cultivated enset were investigated using RAPD, ISSR, AFLP, SSR genetic markers and detected a reasonable amount of variability within cultivated populations. Moreover, partitioning the existing genetic diversity within and among populations of enset also showed higher within population diversity in many of the studies. The trnT-trnF sequence from cpDNA was also used to study Ensete and Musa genotypes and detected 106 informative character that strongly support the species status of enset. The recent diversity analysis on largest set of enset clones (ca. 458) using 120 SNPs showed moderate to high diversity in 12 populations collected from south and southeastern parts of Ethiopia. The development of these genetic markers and its application on diversity assessment could help to identify diverse populations for breeder target collection. Most of the analysis using various molecular markers confirm the long tradition of extensive seed-sucker exchange between enset cultivating communities in Ethiopia and these markers can also be applied on marker assisted breeding to improve the productivity of enset.

In another effort, an in vitro propagation of enset was shown to have paramount importance and applications to conserve germplasm and propagation of virus and bacteria free plantlets. In line with this, research has been carried out to develop efficient micropropagation and transformation methods for enset that can be used to disseminate healthy clones and improve the productivity the crop.
Similarly, with applications of biotechnological tools, appropriate enset processing techniques have been developed to isolate pure enset starch and improve the traditional labour-intensive processing approaches. Moreover, methods for enzymatic hydrolysis and chemical modification of the starch for application in the food, textile, and paper industries has been developed and optimized. Overall, biotechnology and genomics tools have been in use to address production and processing challenges in enset, though they are fragmented in various institutions with limited and unsustainable funding. However, the recently available genome-wide sequence data on enset could accelerate enset research and crop improvement by identifying single-nucleotide polymorphisms (SNPs) that might serve as molecular markers for marker-assisted breeding. Furthermore, the safe use of biotechnology can play a key role in enhancing the productivity and utilization of enset and improve livelihoods by addressing key challenges in enset farming system in Ethiopia.
Challenges, research status and strategy for enset (Ensete ventricosum (Welw.) Cheesman) research and development in Ethiopia

Sadik Muzemil, Zerihun Yemataw and Eshetu Derso, Areka Research Centre, SARI; E-mail: Yemataw.zerihun@yahoo.com

Summary

Enset is called “The tree against hunger” in Ethiopia as it once acted as the key crop against hunger by supplying the main food energy for people of Southern and South western Ethiopia. The production and productivity in enset is affected by various biotic and abiotic stresses. Although the production constraints vary from zone to zone; the major problems are similar in nature. The complexity of problems demands basic strategies and adaptive research to attain maximum production and productivity in enset with an interdisciplinary and holistic approach without affecting the existing ecosystem. The National Enset Research Project was established to address the production constraints in enset and to achieve high production and productivity through basic and strategic research approach in enset. Currently many research centers have been established to cover different agro-ecologies those were not addressed by the project.

The objective of this paper is to review status of enset research and development, and provide strategies for transforming the sectors into an important economic activity for the country. Various research activities have been conducted to generate new production technologies and to promote them to the end users. On the crop improvement for instance: clonal identity using farmers’ classification, collection and maintenance of Enset Germplasm, morphological and molecular characterization of enset clone, evaluation of enset varieties for best quality and yield of kocho, bulla, fiber, amicho use values and drought tolerance. In addition a study also has been carried out to evaluate enset clones for enset bacterial wilt resistance/tolerance. More studies have been conducted on the agronomy part of enset so far. Comparison of whole, halved and quartered corms for planting, frequency of transplanting, spacing for planting enset on permanent field, and soil fertility management on enset fields have been carried out to improve the production and productivity of enset. Attempts were also made to develop regression model which, non-destructively, predicts yield of enset. Concerning issues in relation to disease and pest management options, research findings on disease and pest identification, pathogen characterization (Enset Bacterial Wilt (EBW)), pathogen survival, means of dissemination, pathogenicity test, sanitary control, and identification of some tolerant clones and enset root mealy bug control measures were conducted. Enset production and productivity have shown remarkable growth during the last two decades. Reports have revealed that the area under enset production has increased from 270,000 hectares to 312,171.98 hectares, and is taking up about 2.30% land area covered by all crops at country level and yielding about 7,288,686.96 quintals of produce by the peasant holders, and contributing about 2.68% to the total country-level crop production. Moreover, productivity has witnessed the average yield of refined Enset product (kocho) which increased from 7 to 12 tons ha-1 year-1 to 25 tons ha-1 year-1. This significant increase in production and productivity was achieved through joint
effort of different stakeholders throughout the development of novel technologies and creation of awareness about different technologies. However, the diverse challenges and constraints demand a paradigm shift in formulating and implementing the agricultural research directorate, as growing population, increasing food, feed, and fodder needs, natural resource degradation, climate change, new pests and diseases, slow growth in farm income, and new global trade regulations emerge. In order to sustain the benefits of the research and development, the project is organizing training programs and also other extension activities to sensitize and enhance capacity building of the farmers so as to achieve an inclusive growth, give more focus on the public-private partnership and also empowering the rural women folk through self-help groups, thereby, developing clusters for the improvement of the poor living in the villages. It will also develop collaborative mechanisms at the national, regional and international level and will develop strategies to respond to the change for the benefit of the stakeholders. It will be done in participatory mode so as to involve all the stakeholders for the development of enset production and productivity in the country.

**Key words:** Agronomy, Breeding, Diversity, Enset, Bacterial Wilt
Improving indigenous knowledge of propagation for the development of enset agriculture: promoting farmers’ adaptation capacity to climate change

Laila M. Karlsson¹, Abitew Lagibo Dalbato¹, and Tamado Tana²

ⁱDepartment of Crop Production Ecology, Swedish University of Agricultural Sciences, Uppsala, Sweden; E-mails: email@lailakarlsson.se; abitew.lag@post.com
²Department of Plant Sciences, Haramaya University, Haramaya, Ethiopia: tamado63@yahoo.com

Extended summary

Background

Enset agriculture contributes to soil fertility and environmental sustainability as any perennial crop: avoiding erosion and keeping nutrients and moisture. Enset fields have higher soil organic matter and nutrients than other fields (Tensaye et al., 1998). Similar to forests, enset is a carbon dioxide sink; the extensive root system remains in soil long after harvest. Enset is known as a drought-tolerant crop, it is said that there was no starvation among enset-growing farmers during famines in the 1970th and 1980th (Brandt et al., 1997). As food resource, enset is similar to potato (Mohammed et al., 2013), and it gives the highest yield in terms of edible energy per area and time unit of crops grown in Ethiopia (Tsegaye and Struik, 2001).

Enset agriculture has for long proven as farmers’ adaptation strategy to climate change effects. It has obviously a wide range of economic, social and environmental benefits. Enset propagation, management and food processing techniques rely on indigenous technical knowledge of farmers. As there has not been genotype improvement, as conscious breeding, farmers use the same landraces as always. Areka Research Centre (the national centre for enset research) released six landraces as cultivars with described characteristics. It is necessary to encourage farmers, increase research and extension efforts to maximise the benefits of enset agriculture. Our aim is to provide knowledge for enset agriculture.

Research results

Breeding by crossing and selecting requires dependable method for seed germination. We conducted germination studies based on published information and tested soaking, scarification and other physical and chemical treatments. However, there was no response or negative germination response to these (Karlsson et al., 2013a). When enset seeds were placed on moist sand an average of 25 % germinated, but with large variation (5 55 %) among seed lots from different mother plants (Karlsson et al., 2013a).

Further growth of seedlings was tested in pots with local soil only and with added dry cow manure or a synthetic fertilizer. Manure gave the largest plants after six months of growth, even though the nutrition reserve in the seed was sufficient for three weeks of growth (Karlsson et
al., 2013b). Out of ten seedlings planted directly in the field, with manure, four flowered after 24 months when pseudostem base circumferences were ca. 1.5–2.5 m and plants were ca. 6–7 m high (Karlsson et al., 2013b).

Farmers’ practices of burying corm for sprout production was studied by comparing three methods: keeping the corm entire, part it in two halves or part it in four quarters, in all cases also removing the apical meristem. In addition, we tested the effect of watering on planted corms. All holes were dug 40 cm deep and 50 cm in diameter, refilled with 10 cm softened top soil, corm thereon and above it 15 L of 50/50 % mix of dry cow manure and soil, and covered with soil (farmers usually put the manure on soil surface). Emergence of first sprout per corm occurred 50–112 days after burial, during a period with little rain only (Karlsson et al., 2015), thereafter sprouts grew during the rainy season.

Sprouts from corms parted in smaller pieces emerged sooner, and had more sprouts per corm. The drawback with parting corms in smaller pieces is if there is unusual prolonged drought, since an entire corm will keep its moisture better. The watered corms emerged earlier and the sprouts were more uniform (Karlsson et al., 2015).

Studies of amount of manure to use at corm burial, and performance of individually planted sprouts during further growth are underway, and preliminary results will be presented.

**Discussion**

There is need for further studies on seed germination, and knowledge of flowering, pollination, fertilisation and seed set is important for breeding. Since it is easy to grow seedlings, and flowering can occur within two years of germination, enset would be suitable for conventional breeding.

When talking with farmers, there are some myths on enset cultivation running around, such as: “the new shoots must be planted close to house to get smoke”, “you cannot put manure directly on corm, because it will rotten” and “you cannot water on planted corm, since it will rotten”. These myths are now falsified.

It is important to consider indigenous knowledge; farmers have a lot of inherited knowledge on what is functional. However, just because one way functions it is not a proof it is the best way, and farmers’ practice should be tested systematically. Our sprouts were considerably larger than expected, and farmers who saw them were sure we used some “secret chemical”. Rotten corms may be the results of using fresh (not dry) manure directly on corm. At our field, we provided the enset with direct access to manure, instead of feeding the weeds on ground. Neither the watering gave any rotten corm, instead uniform and healthy sprouts. Of course too much water can cause problem, which is a truth for all plants. After recording of the sprouts, we planted them individually back in the field. The field is far from any house, but still they performed very well. Myths falsified!

Further studies will contribute with more and more detailed knowledge; as with all crops, there is no end of development. However, already now the most recent knowledge can be compiled and merged to existing enset agricultural advice. For corm burial, we provided a brochure in Amharic (Karlsson et al., 2012). Important is to make sure advisers are familiar with enset agriculture so they can contribute with advice meaningful to farmers.
References


Relevant research questions on the crop physiology of enset

P.C. Struik, Centre for Crop Systems Analysis, Department of Plant Sciences, Wageningen University and Research, Droevendaalsesteeg 1, 6708 PB Wageningen, the Netherlands; e-mail: paul.struik@wur.nl

Abstract

Enset (Ensete ventricosum (Welw.) Cheesman) is a perennial crop plant of great economic and cultural importance in Ethiopia, and is widely used for many different purposes, including food, forage, medicine, building material and fibre. Enset is an ideal crop for climate smart, sustainable agriculture, especially in low-input, fragile environments. The main strengths are: prolonged vegetative growth and long canopy cover, recycling of nutrients, drought resistant, stable dry matter allocation pattern (and therefore long period of fitness for use), large storage capacity of starch (both below and above ground), high harvest index, easy vegetative reproduction through numerous, vigorous suckers, and its ability to protect the environment against soil erosion. As a starch producing crop it also has a high radiation use efficiency compared with pulses and oil crops. Finally, it is also tolerant against repetitive removal of leaves for forage and repetitive transplanting to increase the efficiency of land use. Using general ecophysiological models, the crop ecology of enset has been investigated but many relevant research questions have remained untouched. Because of its upright and rigid leaves, the plant and crop architecture of enset are special and deserve to be investigated in more detail by architectural models, such as functional-structural plant models (FSPMs). Through such FSPMs, we can investigate the consequences of (trans)planting strategies and gap filling practices on the performance of the crop, thus evaluating the contrasting approaches in crop management by different tribes in the enset growing regions. Similarly, FSPMs (in combination with ecophysiological approaches of dry matter production and allocation) can be used to assess the effects of repetitive leaf pruning, a practice that is very common in many enset production systems. Moreover, these models should be used for 3D modelling of rainfall interception and water transfers by the individual leaves and the entire canopy, which can help to study water storage in the plant, drought tolerance, water use efficiency and protection against erosion by the crop. Given the low rate of leaf appearance, certainly during later stages of plant growth, the stiffness of the leaves, and the longevity of individual leaves, it is necessary to pay attention to the influence of leaf tearing and tattering on the performance of individual leaves. Effects on photosynthesis and transpiration can be either positive or negative at the level of the individual leaves. Upscaling these effects to consequences for plant and crop performance is essential. Finally, because of the vegetative propagation, it is likely that current crop stands are infected by viruses. Quantifying the yield reduction by such infections and the relation between virus titre and performance can help to assess the need for virus-free planting material.
Status of Research on Enset Diseases and its Management

Adane Abraham (PhD), Department of Biotechnology, Addis Ababa Science and Technology University.
E-mail: adaneab2016@gmail.com

Summary

Enset (Ensete ventricosum) serves as staple or co-staple food crop for about 20 million people in Ethiopia. Its production is limited by a number of biotic constraints, of which diseases collectively take the major share. The most important of these is bacterial wilt (BW) of enset caused by Xanthomonas campestris pv. musacearum which has continued to devastate enset since the 1960’s. The disease has also become a serious threat in banana production in the last decade in other countries such as Uganda. The main method practiced to manage BW in Ethiopia is the use of cultural practices such as crop sanitation, avoiding the use of contaminated tools and destruction of infected plants, usually supported by awareness creation. These practices, although helpful, are in practice are difficult to implement and research efforts were made to develop better management options such as the use resistant enset varieties. However, no success has been registered since nearly all clones evaluated so far were found to be susceptible to BW. Currently, further research efforts are being made to more effectively manage BW using innovative strategies such as the use of transgenic resistance which showed some promise with the disease in banana and bio-intensive integrated disease management which includes biocontrol agents, plant extracts and plant growth promoting microorganisms.

Other diseases encountered in enset are caused by fungi, nematodes and viruses. Fungal foliar diseases are numerous and include leaf spot diseases caused by Phyllostica sp., Pyricularia sp., and Drechslera sp. which commonly affect suckers, seedlings and young plants. In older plants, leaf spots are caused by Cladosporium sp. and Deightoniella sp. Mycosphaerella musicola, which causes sigatoka in banana, and is also known to cause destructive leaf spot on enset. Sclerotium wilt and root rot, caused by Sclerotium rolfsii is also encountered but rare. While some of these fungal diseases can be destructive on suckers, seedlings, young transplants and rapidly growing plants up to two years old, infected enset plants normally tolerate these diseases and recover as they grow older. Hence, mature plants do not have serious foliar fungal disease problems. The common nematodes that attack enset are the root lesion nematode, Pratylenchus goodeyi and the root knot nematode, Meloidogyne sp. Pratylenchus goodeyi is mostly found in association with bacterial wilt of enset and thus may play a role in development and severity of the disease. The leaf nematode caused by Aphelechoides sp attacks leaves of suckers and young seedlings. Finally, viral mosaic and chlorotic streak disease causing severe stunting of affected enset plant has been reported in 1990’s. The association of bacilliform DNA virus has been earlier observed with the disease. Recently, detailed study on enset samples with such symptoms revealed the association of hitherto unreported new badnavirus species with bacilliform particle. Genome sequencing indicated that its DNA has 7163 base pairs with three open reading frames like other badnaviruses. No other virus have yet been reported on enset. Little research effort is made to manage enset diseases other than BW.
To summarize - BW remains the most important biotic constraints in enset production and a nationally coordinated effort should be made to develop integrated management strategies by using traditional and new technologies. At the same time, the extent of damage caused by the other enset diseases should be quantified and research should address their management options on prioritized diseases as some of these could emerge as major ones, due to factors such as climate change.
Enset bacterial wilt (EBW): Towards an integrated management strategy

Getahun Yemata¹, Masresha Fetene², Bruktawit Desta³ and Tesfaye Alemu⁴

¹Bahir Dar University, Department of Biology; ²Addis Ababa University, Department of Plant Biology and Biodiversity Management; ³Ambo University, Department of Biology; ⁴Addis Ababa University, Microbial, Cellular and Molecular Biology Department

Extended summary

Enset bacterial wilt (EBW), caused by Xanthomonas campestris pv. musacearum (Xcm), is one of the most important constraints to enset cultivation and the disease is currently considered as the biggest threat to enset agriculture in the south and south western Ethiopia. Xcm is highly communicable and its spread has endangered the livelihood of millions of farmers who rely on enset for staple and co-staple food. Previous research results revealed the occurrence of EBW disease in all zones of the Southern Nations, Nationalities and Peoples Region (SNNPR) with differing degrees of severity. Unlike other diseases, EBW is both extreme and rapid causing gradually increasing losses over the years. The economic impact of the disease is potentially disastrous because it destroys whole plants leading to complete yield loss. The disease spreads within and across fields by means of contaminated tools, infected plant materials, infested soil, wind driven rain and insects.

Although, EBW can be managed by following phyto-sanitary practices such as burying infected plants, restricting movement of infected plant materials, sterilizing tools and raising awareness about the disease, the implementation of such practices have been inconsistent due to the fact that they are labor-intensive and thus, the farmers are reluctant to implement them. Moreover, there are currently no known commercial bactericides and bio-control agents to control EBW. Therefore, there is the need to search for effective and environment friendly methods of controlling the disease. One such a strategy for bacterial disease control in crops is to improve plant defense mechanisms. This can be achieved by an ecosystem based strategy that focuses on long term prevention of diseases or minimizing their damage through a combination of different biological control techniques. To this end, medicinal plant leaf samples were collected from enset growing areas and bioactive chemicals were extracted using maceration method. The in vitro antibacterial test of crude leaf extracts revealed high potency against Xcm. Extracts of Ricinus communis, Eucalyptus citriodora, Agarista salicifolia, Pycnostachys abyssinica, Laggera pterodonta, Albizia shimperiana and others showed relatively higher antibacterial activity at 200, 100, 50 and 25 mg/mL. Moreover, R. communis extract had the lowest minimum inhibitory and bactericidal concentrations followed by the extract of A. salicifolia. Botanical formulations of these two species were developed at 1 and 2 % and their antibacterial activity was evaluated.

Soil samples were also collected from enset rhizosphere from which arbuscular mycorrhizal (AMF) and Trichodermal fungi were isolated and identified at species level. Approximately, 24 % of the soil sample collections were found to have Trichoderma species. Secondary metabolites
of Trichoderma pure cultures were extracted with chloroform:methanol mixture (1:1v/v) and shaken overnight at 120 rpm at room temperature. After filtration, the solvent was evaporated to 50 % and their antibacterial activity was tested. Most of the extractions showed weak antibacterial activity. One of the pure culture extract exhibited a wider inhibition zone diameter. The compatibility of botanical formulations and the effective Trichoderma isolate was tested and found to be well-matched. This shows that integrations can be made between these disease controlling strategies.

On the other hand, all the soil samples had different number of AMF spores. The highest number of AMF spores were obtained from Emdiber district, Yefuk Tarek Kebele soil sample (636 spores/100 g of soil) followed by Geleso Sore district, Areka 04 Kebele (542 spores/100 g of soil). According to morphotype classification of AMF spores, Areka 04 Kebele soil sample was found to have the most abundant spores of four AMF species, namely; Acaulospora capsicula, Acaulospora gerdemanni, Glomus pansihalus and Acaulospora sieverdingii. The most abundant AMF spores in Yefuk Tarek soil sample belonged to Acaulospora lacunose species. All the five species were multiplied using maize as a host for glasshouse and field applications. The antibacterial activity of Brassica carinata seed extract residue from edible oil factories was also evaluated and found to have anti-Xcm activity at different test concentrations.

Integrated application of these bio-control agents improves the resistance of enset by inducing systemic acquired resistance that involves physical thickening of cell walls by lignifications, deposition of callose, accumulation of antimicrobial low molecular weight substances (phytoalexins) and synthesis of pathogenesis related proteins such as chitinases, glucanases, peroxidases and others. Induction of resistance by the crude leaf extract of A. salicifolia has been found to reduce EBW incidence by 33 % in a susceptible enset clone. Extracts of medicinal plants have also a direct toxic effect on pathogens. Moreover, AMF and Trichoderma can minimize pathogen population in the soil by antibiosis; an interaction that involves the production of low molecular weight compounds that have a direct effect on other microorganisms. Competition is also another mechanism of action of AMF and Trichoderma whereby pathogens are excluded by depletion of a food base or by physical occupation of site.

In general, the study has shown that crude extracts of medicinal plants can induce resistance for Xcm while Trichoderma extract can inhibit bacterial growth as shown in the in vitro tests. Since botanical formulations and Trichoderma have shown compatibility, there is a good reason to use an integrated approach for reducing EBW disease, especially as these bio-control agents are safe and environmental friendly.

Key words: Arbuscular mycorrhizal fungi, Botanical formulations, Enset bacterial wilt, Enset, Induced resistance, Trichoderma isolates, Xanthomonas campestris pv. musacearum
Endophytes of enset: potential applications for the control of bacterial wilt disease and as plant growth-promoting agents

Yemisirach Mulugeta¹ and Amare Gessesse ¹,²

¹Institute of Biotechnology, and ²Department of Microbial, Cellular and Molecular Biology, Addis Ababa University, P O Box 1176, Addis Ababa, Tel: +251-945973703; e-mail: amare.gessesse@gmail.com or amare.gessesse@aau.edu.et

Summary

Endophytes are symbiotic microorganisms (bacteria and fungi) that live inside healthy plants without causing any harm to the host. Many endophytes help their plant host resist different biotic and abiotic stresses. These include protection from attack by pathogens and insect pests; drought and salt tolerance; promotion of plant growth through secretion or modulation of the level of plant hormones; and making limiting nutrients available for the plant. Recently endophytic bacteria and fungi from enset were isolated and their role in promoting plant growth and maintaining plant health was studied. A total of 446 bacterial and 105 fungal endophytes were identified indicating the presence of high diversity. The bacterial endophytes were grouped to four phyla and 53 genera while the fungal isolates were grouped into two phyla and 42 species. Most of the enset endophytes showed one or more plant growth promoting characteristics. Production of the plant hormone indol acetic acid (IAA) was found to be relatively widespread among the bacterial endophyte isolates. Other isolates were shown to produce siderophore or grow on nitrogen free medium, an indication for nitrogen fixation. Some of the bacterial endopynes were also able to solubilize phosphate.

Since the 1970s the emergence of bacterial wilt disease caused by Xanthomonas campestris pv. Musacerum has posed serious challenges to enset-based agriculture. Because the pathogen resides in the vascular tissue of the host plant, chemical based control strategies cannot be effective. Therefore, biological control using endophytes is considered as a useful alternative. In this study, the potential of enset endophytes to control bacterial wilt disease of enset was tested. In vitro different bacterial isolates, especially those belonging to the genera Pseudomonas, Bacillus, and Rhizobium showed marked inhibition of growth of the pathogen, Xanthomonas campestris. Similarly fungal endophytes belonging to the genus Mycosphaerella coacervata and Plectosphaerella cucumerina inhibited the growth of the pathogen. Green house tests using a mixed culture of bacterial endophytes resulted in decrease in disease severity indicating their potential usefulness as biological control agents. Some of the strains were shown to produce volatile organic compounds known to have antimicrobial properties. The data show the potential of enset endophytes in promoting plant growth and health.
Land use changes in the Enset-based agroforestry systems of Sidama, Southern Ethiopia and its implications to agricultural sustainability

Tefsaye Abebe, College of Agriculture, Hawassa University, P.O.Box 5, Hawassa, Ethiopia; E-mail: tesfaye@hu.edu.et

Extended summary

Introduction

Enset (Enset ventricosum (Welw.) Cheesman is a staple or co-staple food crop for an estimated population of 15 million people in the South and South-western parts of Ethiopia. It is cultivated within altitudes of 1500-3100 meters above sea level, in areas having a mean annual rainfall of 1000-1800 mm and a mean temperature of 10-20°C (BODEP, 1997). Temperature plays a significant role in the growth rate of enset. Accordingly, at the altitudinal ranges of 1500-2300 meters (Woyna Dega areas) where mean annual temperature is 15-20°C, enset grows fast and reaches full maturity in 6-8 years. On the other hand, in the high altitudes of 2300-3100 meters (Dega areas), where mean temperature drops to 10-15°C, it takes an average of 8-10 years and even more, to reach full maturity (BODEP, 1997). The major enset growing areas in Southern Ethiopia are, Sidama, Gedeo, Gurage, Hadiya, Kembatta, Wolayita, Gamo, Gofa and Kefficho administrative zones.

In the tropical highland (Woyna dega) zones with altitudes of 1500-2300 m.a.s.l., the diversity of crops is generally high and enset is grown in integration with coffee, fruits, vegetables, cereals, trees and livestock in mult-istorey agroforestry systems. Here, the climatic and soil conditions are suitable for the production of different types of crops, including high value crops such as coffee and Khat (Catha edulis), and it is not clear how farmers allocate their land for the different types of crops in order to ensure attainment of household food security and income. The age structure of the enset crop, which gives an indication on sustainability of food supply, is not also known. This paper attempts to review literature that relate to land use dynamics of the Enset-coffee agroforestry systems, the age structure of enset plantations and the overall effects of these changes on sustainability of the Enset-coffee agroforestry systems of Sidama administrative zone in Southern Ethiopia.

Composition and structure of the Enset-coffee land use systems

Most of the Enset-coffee agroforestry systems of Sidama have evolved from forests. Farmers maintain the upper storey trees and clear the undergrowth to open up space for planting enset, coffee and other crops. More species and varieties of crops and trees are gradually introduced (Tefsaye Abebe and Bongers, 2012). In addition to species diversity, a high level of genetic diversity is found in two major crops, enset and coffee.
The diversity and density of the crops vary spatially and temporally. The agroforestry systems show four distinct vertical layers of crops. Vegetables, spices, beans, root and tuber crops occupy the lowest strata up to 1.5 m. Coffee, enset, maize, khat, sugarcane and some fruit trees, such as banana and papaya, occupy the layer between 1.5 and 5 m. Larger fruit trees, such as avocado and white sapote, some shrubs and pollarded shade trees dominate the third layer between 5 and 12 m., and the fourth layer, above 12 m, which could sometimes extend up to 35 m high, is dominated by timber-producing shade trees (Tesfaye Abebe et.al., 2006, 2010). The lower most stratum is the richest in species (64%); the second stratum is the densest because of the heavy dominance of enset and coffee (Tesfaye Abebe, 2005). The key components of these agroforestry systems are the perennial crops enset and coffee, with mean coverage of over 60% of the farm areas (Tesfaye Abebe et al., 2010).

The high diversity of species, which combines crops, trees and livestock with different uses and production cycles, is considered as essential component of sustainable agriculture because of the wide socioeconomic and ecological roles it plays in the systems. The roles include, among others, year-round production of food and wood products, decreased risks of production failure, increased productivity over time (Netting and Stone, 1996), maintenance of genetic diversity and landscape protection (Perfecto et al., 2009; Trenbath, 1999). Food species with high energy content are dominant crop species in the farms, and enset is the most important staple food crop.

**The role of Enset in the system**

Enset is a multipurpose crop that produces food, fodder, fiber and other products. Food is extracted from the pseudostem and corm since the starch accumulated in the leaf sheaths and the corm are the main products. Three types of food products are namely, Qocho, Bulla and Amicho. Yield of enset varies with the landraces used and with the climate. According to the nationwide survey made on enset production (CSA, 1997), the average yield of Qocho and Bulla per plant is 30.15 and 1.04 kilograms, respectively. Using an average density of 2000 enset plants per hectare and a harvesting age of six years, its productivity will be than 10 tons-1ha–1yr, and this puts it among the highest productive crops in the country. Enset guarantees food security and stability in the household economy in that processed produce can be stored for a long time and live plants can be maintained on farm and harvested any time when the need arises (Almaz Negash, 2001; Admasu Tsegaye, 2002), which is why enset areas are not prone to famine (Desalegn Rahmato, 1995).

In addition to food, enset has many other uses. The fiber extracted during processing is used locally for making strings, ropes and other products, or it is sold in markets for use by fiber factories. The leftover during harvesting as well as the thinnings and leaves of enset are important fodder sources for livestock. The leaves as well as the dry leaf sheaths are also used as packing, wrapping and binding materials. Moreover, some enset landraces are used in human and livestock medicine. Enset also plays a very important environmental role. It protects the soil from erosion and runoff, it serves as shade and improves the microclimate for the undergrowth, and the litter from the leaves and other parts improve soil fertility. Unlike annual plants, small portion of the biomass is taken out of the system at harvesting, while the largest portion is returned directly as litter or indirectly through the manure. In general, enset has ideal attributes for low-input sustainable agricultural production systems: It is high yielding, it can be harvested
any time once it is four years old, it doesn’t require external inputs, it protects and/or enhances the environment, and it has multiple functions. It is, therefore, no wonder that it has been supporting a dense population of over 500 persons per km² in areas where it is used as staple food.

Land use changes in the Enset-coffee systems

Sidama administrative zone is a major enset growing area accounting for 22% of the total enset production area in the country (CSA, 1997). In the Enset-coffee agroforestry systems of Sidama, Enset covers an average of 26.4% of the total farm area (Tesfaye Abebe, 2005), with variation across sites and between farms. The proportion of land allotted to enset is more or less similar across the different wealth groups of farmers. Large farm holders can produce sufficient enset for consumption and allot an increasingly larger area to grow cash crops such as coffee and Khat. Poor farmers have a slightly higher share of land under maize because, with a lower farm size, farmers cannot depend solely on enset, which takes at least four years to mature, but also need early maturing crops such as maize and sweet potato. This illustrates the fact that enset, as the main staple crop of the household, is a strategic crop and determines cropping plans, land use, use of technology and consumption and marketing decisions (Desalegn Rahmato, 1995). If a household has sufficient enset plants for consumption, it grows high value crops for the market; if there is no market, cash crops will be curtailed in favour of food crops. If the number of mature, ready-to-harvest enset plants on the farm is insufficient to feed the family during the year, more land will be used to grow annual food crops such as maize and sweet potato. These additional annual crops are planted in the part of the farm usually allocated for transplanting enset. The nature of enset cultivation lends itself well to such flexible decisions. For the first two years enset is often grown in very high densities of about 10,000 or more plants per ha. If there is ample space, the thinings are transplanted into the new plots; if there is not enough space, the thinings are used as livestock feed or incorporated in the soil.

The crucial decisions that are made by the households to obtain a sustainable yearly harvest of Enset are, the total farm area to be planted with enset and the distribution of enset plants over age classes. In the Enset-coffee agroforestry systems of Sidama, enset is normally harvested after five to eight years. If we take the harvesting age of six years, there will be six age classes of enset plantations each having proportional area coverage of 16.7%. This is not the case, however. In a study of age structure of enset in these land use systems, Tesfaye Abebe and Bongers (2012) found that enset fields are dominated by immature enset plants: about 90% of the plants were less than four years old, while only 10% were five to eight years old. Poor farmers in particular have a smaller area under matured enset. The ratio of mature enset (age older than five years) increased with wealth: 4.7% (poor), 10% (medium) and 17.3% (rich). This confirms that farmers with a smaller area of farmland cannot afford to depend on enset only, as it takes at least four years to be harvested. Poor farmers are therefore forced to fill the consumption gap with annual food crops, such as maize and sweet potato – crops that are often grown as monocultures because of their high light requirement.

As the dry matter yield of enset per unit area and time is much higher than other crops (Admasu Tsegaye and Struik, 2001), and due to the large-scale environmental benefits of enset, research and extension efforts should focus on reversing the declining trend of enset plantations on small farms through a systematic allotment of enset plantations. To achieve this, the number of enset plants sufficient for annual consumption of a household should be estimated, and
that number should be planted every year during the whole rotation period. For instance, if 60 mature enset plants are required for the household’s annual consumption and the rotation cycle (harvesting age) is six years, then a total of 360 enset plants divided into six age categories (1-6) of 60 enset plants each should be grown. At the end of the sixth year the mature 60 plants can be harvested and replaced by new planting materials. This rotation would help to obtain a sufficient and regular yield from enset while maintaining the complex and integrated nature of the agroforestry systems.

In addition to farm size, access to markets also affects farmers’ decision to allocate land for enset production. Farmers with good market access, either because of the physical proximity of markets or good access to major roads, devote a smaller proportion of their land to growing enset and a higher proportion to cash crops. This is because market access enables them to sell the cash crops and buy what they need for subsistence. The variation among farmers and the impacts of such drivers show that the land use systems in the Sidama region are dynamic: farmers make individual choices and respond to emerging challenges and opportunities. When per capita land holding declines, mostly as a result of increased population pressure, farmers tend to produce more staple food crops than cash crops. Among the food crops, they give priority to annuals rather than perennials (such as enset), because of immediate subsistence needs. Farmers also assess their comparative economic advantage and respond to increasing market opportunities, as was manifested in the expansion of khat in the study areas (Tesfaye Abebe et al., 2010).

The enset-coffee agroforestry systems already carry a very dense population, which is still growing fast. The high population growth (2.5%) is likely to result in increased fragmentation of farmlands. This trends are likely to result in a further expansion of annual crops and a reduction in the perennial components (crops and trees) and livestock, which are vital for the sustenance of the system. Likewise, the increasing commercialization of crops such as khat, which is associated with an increased share of annual food crops (maize and sweet potato), is leading to the reduction in the key native perennial crops, enset and coffee. The share of native and ecologically friendly multipurpose trees declines with better road access, while that of eucalyptus tends to increase. This will lead to a further uniformity of the landscape.

Effects of the land use change on productivity and sustainability

A high species diversity which combines crops, trees and animals having different uses and production cycles has a potential to maintain the resource base, the land. Of course, this would depend on the quantity and quality of the inputs used in the system. Many studies propose the use of ‘sustainable intensification’ (Tilman et al., 2002; Pretty et al., 2003; Godfray et al., 2010), which seeks to combine increased production of food from the same area of land with a reduction in environmental impacts (Royal Society of London, 2009). While the enset-coffee agroforestry systems of Southern Ethiopia display the characteristics of sustainable agriculture, there is room for increasing productivity through intensification. If intensification involves a reduction in plant diversity and the perennial nature of the systems, leading to the development of monoculture fields, this could disrupt the ecosystem services provided by the integrated multistorey agroforestry systems. However, integrating high value crops into the systems without significantly affecting the composition and diversity of components could lead to sustainable intensification. Hence, maintaining the existing components of the enset-coffee agrofor-
Enset systems would contribute to its ecological and socioeconomic sustainability. Ecological sustainability indicates the extent to which natural resources are conserved so that farming can be continued, while economic sustainability shows its suitability and adaptability to local farming conditions and its economic viability (Pretty et al., 2003; Ojiem et al., 2006; Peyre et al., 2006; Holden and Linnerud, 2007). Below, we evaluate the ecological and socioeconomic sustainability aspects of the enset-coffee agroforestry systems and justify the need for their maintenance.

**Ecological sustainability aspects**

Several features of the enset-coffee agroforestry systems are important for the ecological sustainability, including (1) maintenance of species diversity, which is important for risk spreading and minimization, genetic conservation of native species, efficient resource use and biological pest control; (2) reduced use or elimination of soluble or synthetic fertilizers, increased or improved use of manure and other organic materials as soil ameliorants, and soil conservation; (3) reduced use or elimination of chemical pesticides, replacing these with integrated pest management practices and system diversity; and (4) self-sufficiency, by using on-farm or locally available ‘internal’ resources and a minimum or conditional use of purchased ‘external’ resources, which contributes to the long-term conservation of the resource base and environmental resilience of the systems (Tesfaye Abebe et al., 2006; Tesfaye Abebe and Bongers, 2012).

**Socioeconomic sustainability aspects**

The maintenance of high species diversity in the enset-coffee agroforestry systems also contributes to socioeconomic stability. As in other agroforestry systems, the diversity of crop, tree and livestock species with different uses and production cycles enables the year-round production of different products, reduces the risk of production failure, allows flexible use of labour and enables efficient cycling of locally available resources, which means that production does not depend on external inputs (Kumar and Nair, 2004; Tesfaye Abebe, 2005). Moreover, the enset-coffee agroforestry systems also possess several specific features that promote socioeconomic sustainability. They not only have a high species diversity, but also a high diversity in functional crop types, notably staple food crops and cash crops, in addition to the usual supplementary home garden crops (Tesfaye Abebe et al., 2006). The carbohydrate-rich basic food crops enset and maize are supplemented by pulses, vegetables, fruits and animal products that provide proteins, fats and vitamins, and by trees that provide resources for construction and household energy. This is of crucial importance for households, especially poor families. The cash crops coffee, khat and pineapple that are incorporated into the systems, also give a more balanced household income. Both the diversity of crops and the inclusion of the perennial enset spread the risk to households of individual crop failures. The possibility of flexibly harvesting enset as a staple food is one of the main reasons why the Southern highlands of Ethiopia are relatively free from hunger (Desalegn Rahmato, 1995; Brandt et al., 1997).

Like the ecological sustainability of these agroforestry systems, its socioeconomic sustainability cannot be explained by its species diversity alone, but also by the specific features of the two key species enset and coffee. Enset is both a food crop and a provider of different products, such as fibre and fodder. It is therefore ideally suited to low-external input agricultural production systems (Almaz Negash, 2001; Bizuayehu Tesfaye, 2002), while its high productivity and
multiple functions provide sustenance for a very dense population, which is often two to three times higher than in the cereal-based systems found in other parts of Ethiopia (Tesfaye Abe e, 2005). Coffee serves as a main cash crop supplementing the mainly subsistence-oriented enset production. Consequently, not only from an ecological point of view, but also from a socioeconomic point of view, coffee and enset can be considered as key species.

Conclusion and recommendations

The traditional enset-coffee agroforestry systems are characterized as a sustainable land-use system, but this does not mean that they are not subject to change. Decreasing farm size and increased commercialization is affecting the systems. The shift from the traditional enset-coffee systems towards inclusion of other food and cash crops has increased household income. However, the expansion of open-field food crops (maize, sweet potato) and of monocultural cash crops (khat, pineapple), causes not only a gradual loss of species diversity and tree biomass, but also a decrease in the perennial crops and native tree species, to the detriment of the dominance of the two key species, enset and coffee. As these are considered to play a significant role in the stability and resilience of the agroforestry system, it is expected that the land use change will have negative impacts on the landscape. It results in a gradual reduction of the ecological benefits derived from these integrated and complex systems, which threatens their long-term sustainability. We should therefore opt for the maintenance of the perennial component in systems and the integration of new crops into the existing multistorey system, without affecting the biodiverse nature of enset-coffee agroforestry systems and without losing their essential key species, enset and coffee. This can be achieved through directed extension services by government institutions and local organizations. Additional research should focus on the integration of expanding cash crops (such as khat and pineapple) into the existing systems without changing the multistorey structure of the home gardens. As enset produces the highest volume of food per unit area and time, and because of its different end uses and diverse ecological roles, the future of these home gardens depends on the maintenance of enset-based staple food production. Thus, strategies should be developed to reverse the increasing dependence on maize and enhance the systematic production of enset.

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The diversity, challenges and management of enset (Ensete ventricosum (welw.) Cheesman) by the Kembatta people, Southern Ethiopia.

Melesse Maryo\textsuperscript{1} and Sileshi Nemomissa\textsuperscript{2} and Tamrat Bekele\textsuperscript{3} \\
\textsuperscript{1}Dilla University, Department of Biology email- melessedevid@gmail.com, \\
\textsuperscript{2}Addis Ababa University, Faculty of Life science e-mail- nemomssa@bio.aau.edu.et; \\
\textsuperscript{3}Addis Ababa University, Faculty of Life science e-mail-tambek@yahoo.com

Summary

Enset (Ensete ventricosum (Welw.) Cheesman) is an endemic Ethiopian multi-purpose crop with environmental and socio-cultural significance. It has a potential for food security as it grows in areas where there is a high population pressure and limitations of cultivable land, mainly in south and south-western parts of Ethiopia. Nonetheless, studies indicate that poor attention by the current extension system, food preferences, decline in soil fertility, climate change, impacts of pests and diseases, and focus on cash crop cultivation are challenging the diversity of enset landraces and the sustainability of enset agriculture in Ethiopia. A survey on diversity, challenges and management of enset was conducted in Kembetta Tembaro Zone, Southern Ethiopia. In total, 12 farmscapes were selected from the study area. At each farmscape, 15 sampling sites (farmlands owned by households or HHs) were randomly selected, making total sampling sites 180. The total enset landrace composition was determined by making a presence-or-absence record in farms of each sampled HH. In order to investigate the pattern of diversity that exists in the area the identification of enset landrace and recording of basic information such as farmers’ preferences, criterion for landraces identification, and the cultural management practices were recorded with the help of farmers. The characters of enset landraces such as storability, resistance to enset bacterial wilt, and the yield were used to evaluate the knowledge of farmers on use values of the landraces. Interviews, questionnaires and group discussions were also used to collect the data. Enset landrace diversity in the farmlands was estimated by Shannon Index ($H'$). The linear multiple regression was employed to determine the effects of biophysical and socioeconomic variables on enset landraces using IBM SPSS ver.20. ANOVA was computed to examine any significance differences in enset landraces among wealth groups and agroclimatic zones. The study result indicated that farmers’ characterization identified a total of 111 named enset landraces, of which 21 have different medicinal values. There was high significant difference (P< 0.01) in enset landraces among the three economic classes, and the three agroclimatic zones. Poor farmers grow few number of landraces, and the number of enset landraces was related to the farmland and livestock sizes. The mean number of enset landraces in the Zone was 7.2/HH. Dega agroclimatic areas cultivated twice the number of enset landraces in Kola areas (mean = 11.5/HH). The highest number of enset diversity was recorded from an altitude of > 2500m asl where there were optimum conditions for enset growth and where it served as the main staple crop. The enset plantation area that was confined in the homegardens of the study area ranged from 0.01 to 1.25 ha with a mean of 0.24 ± 0.02 ha but enset plantation covered 9% of the total crop land in the study zone. The number of enset landraces per
farmscapes ranged from 8 to 61 with an average of 27.3, whereas the mean Shannon diversity (H') and evenness (E) indices were 1.84 and 0.64, respectively, in the Zone. Multidimensional preference ranking showed that the use values of enset, particularly amicho, fiber quality, storability, yield, and earliness were useful in discriminating enset landraces. The enset landrace diversity was found to increase with increase in access to market and wealth status of the households but decreased with increase in off-farm activities. However, there were challenges that influence sustainability of enset agriculture, including wild mammalian pests, enset diseases, particularly bacterial wilt, shifting to cash crop, and shortage of farmland. In order to protect and conserve the richest enset landrace diversity in the country, scholars in ethnobotany, microbiology and genetics should work together for a realistic workable solution.

**Key words:** amicho; enset disease; farmers’ characterization; kocho; landraces; multidimensional preference; wealth status.
Nutritional Profile of Enset based Food Products: Current Knowledge, Research Gaps and Future Directions to Exploit its Nutritional and Health Benefits

Ashagrie Zewdu, Assistant Professor of Food Science and Nutrition, Addis Ababa University, Tel: +251911194508; Email: ashuyz1@yahoo.com, Addis Ababa, Ethiopia

Extended summary

Root and tuber crops are widely cultivated in Ethiopia and support a considerable portion of the country’s population as source of food. Among these, Enset, Anchote and some Yams are endemic to Ethiopia. Due to its drought tolerance and high productivity, Enset is regarded as a priority food security crop in Ethiopia. Enset is also known by the name of “tree against hunger. For instance, regions where Enset is used as staple food are usually less affected by the recurrent drought periods. However, Enset is consumed by only 20% of Ethiopian population. The main reasons to its limited cultivation and consumption could be related to uncommon inherent sensory attributes for non-consumers, nutritional inadequacy/lack of some important nutrients (such as vitamins, protein and fat) and its short shelf life.

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 the grated corm (underground stem base). Bulla is the small amount of water-insoluble starchy product that may be separated from Kocho during processing by squeezing and decanting the liquid. Amicho is the fleshy inner portion of the enset corm, which may be cooked and eaten separately, tasting similar to potato.

Few authors have determined the nutritional contents of Kocho and Bulla. Fresh Kocho contains 47–62 g moisture per 100 g. Per 100 g dry matter the approximate composition of Kocho has protein 1.1–2.8 g, fat 0.2–0.5 g, carbohydrates 95–98 g, fibre 2.3–6.2 g, ash 1.7 g, Ca 60 mg, P 68 mg, Fe 7 mg, thiamine 0.06 mg, riboflavin 0.08 mg, and niacin 0.6 mg. While Bulla has a moisture content of that ranges from 44 to 55 g per 100 g fresh material. Per 100 g dry matter the approximate composition of Bulla has protein 0.4–0.8 g, fat 0.2–0.4 g, carbohydrates 93–98 g, fiber 0.6–0.8 g, ash 0.2 g, Ca 91 mg, P 44 mg, Fe 5.8 mg, thiamine 0.02 mg, and niacin 0.2 mg.

As reported by Agren and Gibbson (1968), the main feature of Enset foods is their high energy values (1410–1950 kJ/100 g dry matter of Kocho, 1580–1850 kJ/100 g dry matter of Bulla), derived almost entirely from carbohydrate. Pijls et al. (2006) reported that Bulla is more energy rich (850 KJ/100 g) than Kocho (650 KJ/100 g). Since 45-65% of energy requirement of adult person per day should be from carbohydrates, Kocho and Bulla would be ideal products for nutritional security. Adequate amount of soluble fiber obtained from Enset is important for normal functioning of the intestinal tract, reducing cholesterol level and preventing constipation.
Moreover, Kocho and Bulla are rich in Ca and Zn compared to other similar foodstuffs and contains comparable concentration of Cu, Fe and Mn. For example, when compared with staple cereal grains of Ethiopia, the concentration of Ca in Kocho and Bulla is as good as with barley flour and wheat flour. As compared to “Red Tef” flour from Ethiopia, Kocho and Bulla contains lesser amount of this mineral; whereas maize flour contains least amount of this mineral. “Red Tef” contains the highest amount of Fe followed by Kocho; while Bulla, whole wheat, maize, and barley white flour contains comparable Fe concentration range. White wheat contains the least Fe concentration range. Generally speaking, mineral contents of Kocho and Bulla satisfy the individuals’ need equally with cereal flours. Fortunately, content of anti-nutritional factors (such as phytate and tannin) are less in tuber crops as compared to cereals and legumes. Hence it would be expected that minerals from obtained from bulla and kocho would be easily bioavailable to the body.

Unfortunately, all Enset foods have low protein content (0.4–2.2 g/100 g) lacking very essential amino acids like lysine. Moreover Enset has Low fat and no vitamin A (fat soluble vitamin). Other vitamins are found in trace amount and are produced during Enset fermentation. This indicates that people who depend only on Enset will be exposed to Protein Energy Malnutrition (PEM) and Micronutrient deficiency (Hidden hunger). Moreover important fatty acids such as Omega 3 and omega 6 Fatty acid which are important for brain development are lacking in Enset Food products. Therefore, foods from Enset source in general need supplementation with other rich source of protein and fat foods like meat, egg, milk and legumes. This might be the reason that Kocho is mostly consumed with “Kitfo” (minced meat) and cabbage by the community who use enset as a staple.

Research Gaps and Future Directions

Fortification of enset based products with protein, vitamins and some minerals either through blending with other legumes and cereals (Food to Food Fortification) or supplementation should be evaluated.

Bio-fortification of enset with pro-vitamin A (β-Carotene) similar to what is done in orange fleshed sweet potato (OFSP) should be evaluated.

Preservative techniques such as the use of modified atmosphere packaging, chemical preservatives, storage temperature etc should be evaluated to improve the shelf life of enset.

Enset starch for industrial purpose (glue, fiber, etc) should be evaluated.

According to indigenous ethno-medicinal values, enset is used for strengthening women after delivery, healing bone fractures in humans, curing stomach cramps and as animal feed to cows to facilitate placental expulsion (Olango et al., 2014). These hypotheses should be investigated.
Biotechnological studies and Yeasts and Bacteria associated with kocho, an Ethiopian fermented food from Ensete ventricosum

Dr. Genet Birmeta, Institute of Biotechnology, Addis Ababa University; P.O.Box 32853, Addis Ababa, Ethiopia; E-mail: Genetbir2@gmail.com

Summary

Enset (Ensete ventricosum W. Chessman) is a traditionally-fermented staple food consumed by a large number of the Ethiopian population although its corm is consumed fresh in some enset clones. It is very important crop as it is drought resistant. Enset food can be harvested at any time when other crops fail and is stored for longer period thus is available all year round. While the crop has such importance not much research has been done on it until recent time. The crop diversity is highly threatened by the devastating bacterial wilt disease caused by Xanthomonas campistris and enset food products are often spoiled by spoilage microorganisms during storage affecting their quality. The starchy food is fermented spontaneously by the action of microbes through traditional practice of burying it in underground pit. The author has conducted researches on various aspects of enset including study on the genetic diversity of cultivated enset clones and wild enset in Ethiopia; development of in vitro micropropagation and genetic transformation protocols crucial for enset improvement; and identified microbes associated with enset and systemic microbes that are resistant to surface sterilization and antibiotics during in vitro aseptic growth.

The author also cultured and identified yeast species and lactic acid bacteria from kocho (enset food product) using ITS and 26S rDNA sequencing and investigated the microbial dynamics at three different stages of fermentation. The microbes identified have beneficial and harmful effects. In fresh Kocho, the most frequent species were Issatchenkia scutulata var. exigua, Geotrichum silvicola and Pichia fermentans. The mid-term fermented kocho (three to four months) was dominated by G. Silvicola, Candida ethanolica and an unknown species (the closer match in the database (89%), was Candida rugopelliculosa which is important in solid waste composting. In the long-term fermentations (seven to 12 months), the most frequent yeast was Candida silvae. None of the dominating yeasts except G. silviloca was found in the long term fermented enset material. Similarly, looking at lactic acid bacteria, in fresh kocho, Lactobacillus plantarum was dominant while in the mid-term fermented kocho, Leuconostoc mesenteroides and L. plantarum were the dominating organisms. L. plantarum and L.mesenteroides have antimicrobial activities useful to prevent growth of unwanted microbes. In the long-term fermented food, Acetobacter pasteurianus and L. plantarum were the most abundant. The spontaneous fermentation of enset could be accounted to the yeasts C. ethanolica, C. silvae, I. scutulata var. Exigua, P. fermentans and G. silvicola and the rather highly dominant lactic acid bacteria L. plantarum and the less frequent A. pasteurianus. These microbes can be good candidates for the development of starter culture. However, their medical importance should be taken into consideration. Some of the microbes such as C. ethanolica, Bacillus simplex and Lactobacillus buchneri identified promote plant growth and productivity and improve soil quality and thus may be used as biofertilizers. In addition, C. ethanolica often acts as a bio-control...
agent against bacterial wilt and is useful in biogas production. The results suggest continued research on biological control of bacterial wilt of enset and isolation of important yeasts and lactic acid bacteria with biotechnological potential.

Regarding the hygienic and health aspects, in the long-term fermented food, the dominant species was the spore forming bacteria of the genus Bacillus. Candida spp. are the most common infectious fungal species in humans; *G. silvicola*, *L. pseudomesenteroides* can be pathogens. A critical finding was the rather high number of the pathogen *Bacillus anthracis*. Hence, in enset growth and food processing, hygiene and sanitation are very important, as well as other public health measures for environmental health.
The Enset Field Gene Bank Initiative: A viable option to conserve the invaluable tuber crop sustaining millions of households

Dr Gemedo Dalle and Dr Feleke Woldeyes, Ethiopian Biodiversity Institute; E-mail: gemedod@yahoo.com; felekewoldeyes@yahoo.com

Summary

Enset (Ensete ventricosum) is a banana-looking perennial herbaceous plant with diverse uses. The multipurpose plant is of functions that range from the subsistence to the ecological and from the economical to the spiritual and rural households in southwestern Ethiopia. The farming system in the region is known to be dominated by enset-based home gardens in which a diverse mixture of crops is concurrently cultivated. Enset and associated local crops support the lives of the largest proportion of more than 15 million inhabitants of the South Nations Nationalities and Peoples Regional State (SNNPRS). Nevertheless, this highly important crop plant and the sustainability of the farming system where it thrives have been threatened due to neglect or improper attention given to the tuber crop. Replacement by fast-maturing crops like cereals and newly introduced temperate fruit crops as well as attack by disease and pests are recognized to be major problems that pose threat to enset cultivation. The Ethiopian Biodiversity Institute, as a primary government entity responsible for the conservation of biological resources of the country, has been engaged in activities that aim at tackling the challenges that enset cultivation is confronted with and also conserving the tuber crop, the associated biological diversity and local knowledge. One approach, in this connection, has been maintaining collections of farmers’ enset varieties in field gene banks. With such premise, an Enset Field Gene Bank was started in Angecha District of the SNNPRS. Besides enabling to maintain dozens of enset varieties, the ex-situ conservation approach has been instrumental in improving awareness on the benefits of the crop plant by a range of stakeholders. Moreover, the participatory undertaking has motivated farmers in the area to maintain more varieties of the tuber in their farms and has helped some community members engage in enset products related trading activities and generating income. The practice is being considered to be expanded to other enset-growing areas of the region so as to ensure continuous dominance of the multipurpose tuber crop in the traditional landscapes. Community members, who take the credit for making enset an integral component of the farming system of the region, will remain active participants in the process; and the conservation endeavor is hoped to contribute towards improvements in local livelihoods and sustainability.
Enset (Ensete ventricosum) Ethnobotany: Research Trends, Gaps and Hints to Forward Steps

Zemede Asfaw, Department of Plant Biology and Biodiversity Management, Addis Ababa University, P. O. Box 3434, Ethiopia; Tel: +251 911959903; Email: zemede.asfaw@aau.edu.et, zasfaw49@yahoo.com

Extended summary

Enset (Ensete ventricosum) is an ethnobotanical icon considering its economic, sociocultural, environmental and symbolic roles. This paper attempts to see how far the Enset research done so far and ethnobotany have been brought to a common front/platform. Considering the scope of studies and the current methodological advances in ethnobotanical research, it is good to see how far previous Enset research has benefited in data collection and analysis. It then looks at the current trend in Enset ethnobotanical research, further continuing to focus on the research gaps from sustainability and development perspectives. Finally, the paper makes a turnaround to seek innovative research directions that could succinctly target the major gaps. It makes further attempts at giving plausible hints in order to address the desired forward steps in Enset ethnobotany research. The ideas brought up can be the basis for embarking upon an innovative research focusing on its ethnobotany as part of an integrated mega research on Enset.

Key words/phrases: Enset culture, agroecology, quantitative ethnobotany, common research protocol, meta-analysis, ethnobotany modeling

Introduction

Enset (Ensete ventricosum (Welw.) Cheesman, Musaceae) is one of the major staple/co-staple food crops with many more use values and widely cultivated in the southern and southwestern parts of Ethiopia. This crop species is cultivated in a wide range of agroclimatic zones all the way from about 1200 to 3100 meters above sea level; having critical roles in the livelihoods of about 20 million Ethiopians. It provides a range of services as food, forage, medicine, environmental health and has a number of socio-cultural roles serving as a symbol for expressing condolence and other rituals (Gebre Yntiso, 1996). It is a species where farmers recognize individual plants in their garden and the human-plant bondage is extremely strong partly due to long history of use by different cultures. The role of human culture in agrobiodiversity becomes visible in the reciprocal interactions with human communities. Thus, it is an ideal plant for application of a mix of qualitative and quantitative ethnobotanical approaches in research in order to explicate the knowledge encoded in the stories, poems, rituals and a wide array of other practices.

Ethnobotany has a collection of research tools and techniques appropriate for the study of indigenous botanical knowledge of useful plant species. It becomes even much more useful with many practical values when the plant of interest is a food crop, indigenous, has long history of use in multiple cultures as food, as part of traditional medicine, in the peoples’ material culture and many other use values. Enset (Ensete ventricosum) satisfies all these and other related attributes and would greatly benefit from a full-blown comprehensive ethnobotanical investigation. One of the main reasons why ethnobotanists and ethnoecologists concern
themselves with the collection and analysis of indigenous and local knowledge on crop species and their ecology is to be able to present the knowledge in a scientifically sound format. Indigenous botanical knowledge retrieved and organized following scientifically permissible procedures is critical as a source of evidence to justify the scientific worth of such knowledge. It also helps in the enhancement of the crop and builds its scientific profile further firming up our understanding in a scientific context, and then applying it for improving the production and utilization of the particular crop species. In this regard, it would be good to see how far we have come or lagged back in the case of enset, a staple, an emblematic, symbolic and charismatic species seen as a common element in the living compounds of southerners, northerners, westerners and easterners even in today’s Ethiopian realism.

Current Trends in Enset Ethnobotany

Brief scanning of the rather voluminous Enset literature shows that some studies have touched upon its ethnobotany even though most of the early works neither called it as such nor applied standard ethnobotanical/ethnoecological methodology. These may not be tagged as ethnobotany. Furthermore, many of the studies that reported on the crop’s ethnobotany-like narratives tended to be more of compilations of checklists and short profiles of vernacular names of clones (farmers’ varieties/landraces) shaped over generations and maintained for millennia. Another aspect that went on being researched was the utilitarian aspect of the different parts of the plant as well as of the standing crop. There has been a lot of interest to understand enset and its system right from the days of James Bruce by foreign and resident researchers of different disciplinary areas. Some among these researchers have applied limited methods of ethnobotany (Yemane Tsehaye and Fassil Kebebew, 2006) often with botanical, agronomic and anthropological biases/perspectives. At most, such studies were overwhelmingly dominated by utilitarian and qualitative approaches that fall into the general category of basic qualitative ethnobotany. The primary reason for the dominance of such approaches is the underdeveloped nature of ethnobotany at global level in general and in Ethiopia in particular.

Major Enset Ethnobotany Research Gaps

The ethnobotany of Enset has been touched by many research works in one way or the other, albeit the disconnected and variable nature in contents, scope and methods. This is mainly because a full scale cross-cutting enset ethnobotany has never been done across all cultures and agroecological zone of its production and food systems. The limited ethnobotanically-oriented studies have generally been incomplete, lacked adequate coverage. There has been no formal research with the primary goal focused to the ethnobotany of this crop. The studies have generally been ancillary to other studies, of incomplete coverage and methodological imperfection and disparities. How the ethno-knowledge corresponds among the Omotic, Nilotic, Cushitic and Semitic communities and ethnicities, though of academic and practical relevance, has not been satisfactorily addressed. Some studies of Enset ethnobotany were done on isolated sites and cultures and fail short of providing a complete and bigger picture while others were published in languages other than English, notably the works by some Japanese researchers. Since Enset cultivation enjoys a wide north-south, west-east and altitudinal stretch engaging different ethno-linguistic communities, a much richer ethnobotanical and ethnoecological role can be hypothesized. There is, therefore, a real need to examine the depth and breadth of Enset ethnobotany in the different cultures and agroecological zones re-defining new approaches and
methodologies. The research gaps can be seen under lack of sufficient cross-disciplinary data and paucity in the application of a broad range of ethnobotanical methods derived from botany, ecology, anthropology, economics and related fields. Application of mathematics, statistics and computational tools is at low levels.

**Hints to Plausible Forward Steps in Enset Ethnobotany Research**

These gaps need to be addressed through application of comprehensive quantitative ethnobotany. The areas of enset cultivation have to be matched with the new agroecological zones of Ethiopia (MoA, 200) and the ethnic identities to be handled by the method of meta-analysis of the data from all areas. Such an approach will show the aspects of similarities among them and between areas as well as the differences. Unless a full scale quantitative ethnobotany is applied, it will not be easy to unwind the “story” of enset, which has been written up by generations of farming communities and a legacy inherited from their hunter-gatherer ancestors of present day enset farmers. The knowledge we are trying to capture and analyze has been cumulating for thousands of years and will not give in hands unless the state of the art of ethnobotany has been applied in research for a better future with continued service to the people while being served by the people. Thus, this section of the paper pledges to provide hints to the desirable forward steps. Here, a preliminary brainstorming has been made to generate some ideas (including wild ideas by thinking outside the box) about the kind of research direction anticipated to take up after thorough discussion among peers.

1. Identify the major Enset cultures areas, their area coverage, cultural significance of enset and other such sets of attributes on the one hand and those cultures considered marginal or peripheral as the crop looms today;
2. Use same ethnobotanical research protocol to study enset ethnobotany of the Sidama, Welayta, Gamo, Keffa, Aari, Gurage, Sheko, Gedio, Oromo, Kembata, Timbaro, Halaba, Hadya, Siltie, Konso, Dawro, Konta, Dizi and other such cultivators and users to assemble Enset ethnobotany;
3. Use GIS data and generate distribution maps taking the zones and weredas and superimposing to them the new agroecological zones and the cultural groups/ethnicities to see the results of interaction between agroecology and culture. Superimpose on zonal/wereda maps, study sites (kebeles), agroecology, language/ethnicity and other comparison parameters. Agroecological zones very central to Enset can be treated as one layer and those that are marginal or peripheral to Enset cultivation can be shown as a second layer. Lower, upper, northern, southern, western, and eastern limits of the Enset farming complex would be marked. Then, randomly select areas with similar agroecologies but different ethnicities and carry out full-blown quantitative ethnobotanical study in all parts of its production zones with the same set of structured interview questions making a common research protocol. An overall meta-analysis of the resulting quantitative ethnobotanical data would provide comparative results across cultures, agroecologic zones, ethnicities and other units;
4. Carry out key informant interview in each area with semi-structured interview questions focusing on community-recognized Enset conservators and heavy users of its products;
5. Do further guided ethnobotanical field tour by interviewing farmer conservators as local experts about their Enset clones, the farming systems and ethnicities and generate quality data through ranking exercises (simple, preference, direct matrix ranking, paired and triadic comparisons);
6. Working in the major ethnicities (>20), preparing checklists of local vernacular names of Enset and its clones identified by farmers with their uses, adaptation, agroecology in each area and comparison of different data sets. In this exercise, cognate names of clones in similar cultures have to be carefully followed up with a native speaker of multiple languages;

7. Mapping the food, medicinal, environmental, fodder, emblematic/cultural and other roles of Enset and its clones;

8. Sorting similar ethno-varieties, use categories, management and cultural (cosmovision) blocks and likewise taking the differences and generalizations that can be drawn up for hypothesis testing in either case;

9. A multi-stage analysis can be conducted by considering individual ethnic communities in isolation and as a constellation of related language families/cultures under Semitic stock, Cushitic, Omotic and Nilotic families;

10. Study the crops associated with the Enset cultivation system looking at their complementarities, companion and associations and this must include the ethnobotany of wild enset known as epo in Keffa;

11. Use the agroecological, agrobiodiversity and ethnicity data to do ethnobotanical modeling (Benifez et al., 2016) of the Enset production system in Ethiopia.

References


Initiatives on Enset research together with the grassroots - In order to sustain and develop the assets for the coming generation

Asnaketch Woldetensaye, DEQOT NGED (Develop and Engage with Quality and Original Treasures), Ölandsresan 6, SE-757 55 Uppsala, Sweden.
E-mail: asnaketch.woldetensaye@deqotnged.

Extended summary

Since the late 70’s research on Enset has been going on within different disciplines. The investigations that are conducted have focused on assessment studies such as uses of Enset and some agronomic studies. However, results gained up-to-date have not been well implemented in practice and or spread well. This is maybe partly because investigations that have been conducted to date were focused on individual researcher’s interest and or not related to sustainability and towards development issues.

Therefore, during 2012, an initiated innovation oriented Enset project was launched that can lead to development program. For this purpose, operational groups were identified and communicated. The groups are composed of researchers from five universities, one local Non-Government Development Association (NGDS) and Enset farmers. The choice of innovative approach of Enset research program is because, despite the importance of Enset to Ethiopian economy and food security, research on the system sustainability and improvement of the cultivation system and processing of its products have not been promoted as was expected. This is partly because the time needed to prove the system sustainability and the cost for research activity are higher than the traditional (example, annual crops) research schemes.

The project program is entitled “Enhancing a Nutritional and Sustainable Ethiopian Treasure”. The main objective of the project is to establish socially acceptable, economically viable and environmentally sustainable Enset production and processing systems.

Today, perennials are recognized as future food security crops as they maintain and improve the quality of soil. Questions such as; “Is Enset cultivation one of the climate friendly production system that exist in Ethiopia?” could be raised. The project will address evaluation of agronomic data, identification of cultivars and their suitability for different types of soil, fertilizer and altitude, and processing methods that keep the nutritional value of Enset. This could be achieved by: exploration methods on using primary products and value-chains of Enset and uncover the potential for processing Enset products.

The research program will be carried out in three phase for six years each. The first phase will involve; 1) field experiment in four different districts (each having three different experiment sites) within three different zones (in Southern Nations, Nationalities and Peioples)
and, 2) study excluding field experiment in nine districts within three regions (Gambella, Oromia and Southern Nations, Nationalities and Peoples). The stakeholders above are meant to engage in the first phase of the program with different discipline and specific objectives with 36 different tasks put under seven different work packages (WPs) including the experiment (see Figure 1). Engaging the grassroots such as researchers, local NGO’s and Enset farmers in the project is expected to play a crucial role in getting many worthwhile issues/problems within Enset farming activities. The group can take the lead on developing initiatives that connect actors with an interest in, and ideas on, finding an innovative solution to a shared problem.

Multidisciplinary project involving different stakeholders such as farmers, researchers, development organizations, etc. is projected to produce easily accessible end-user scientific data that can be shared and or spread easily. Therefore, in order to ensure food security in Ethiopia, there is a need for sustainable intensification of agricultural production systems towards supporting productivity. Smallholder farms are important part of the solution and they must be supported to improve productivity and sustain the improvement.

Figure 1. Multidisciplinary research approach for enset (thematic)
Changes and development of Ensete landrace diversities in South Omo: Observation of indigenous agricultural activities for the last 30 years

Masayoshi Shigeta, DSc. Professor, Graduate School of Asian and African Area Studies, Kyoto University, JAPAN, 46 Shimoadachi, Yoshida, 606-8501, KYOTO, JAPAN;
E-mail: shigeta@jambo.africa.kyoto-u.ac.jp

Summary

Aari people in Ethiopia are known for maintaining high landrace diversity of starchy root crop called enset. Enset (Ensete ventricosum, MUSACEAE) originated in the southern part of Ethiopia and has been serving as the staple for large number of population for long period of time. The crop is important not only for food but also for various purposes; leaves, stems, and fibers are used for weaving, matting, covering, tying, animal feeding and many others. Aari community holds over 100 named local landraces (local varieties) while each farmer cultivates three to 18 different landraces in their gardens. The frequency of landraces distribution among the community is not even but rather exponential; i.e. a few very popular landraces with majority of less common ones. The knowledge of landrace names among male members are acquired from the age of five to six years and gradually increase till the age of 16 to 18. From the observational data, female population seems to gain the knowledge of enset landrace name earlier than male. There are also generational gaps in the knowledge level of landrace-related information. Biological characteristics are key elements of landrace cognition by Aari people. They also recognize the use value of landraces depending on their way of usage. People do maintain less productive landraces regardless of their food production yield. Some landraces are known to produce more starch from the pseudostems, others are preferred for their large underground corm. However, some Aari cultivate one peculiar landrace called Yntada, though small in number, and maintained over the generations. The etymology of the landrace name Yntada can be explained as meaning “it goes (grows) by itself”, since this landrace does not have the monocarpic characteristics but propagates using its sucker like bananas. Taking one minor but peculiar landrace of enset, Yntada, as an example, the process of intergenerational learning and sharing among the Aari community will be discussed. Existence and maintenance of minor landraces such as Yntada among the Aari can be explained as the resultant status created by certain type of action, i.e. cognitive selection. From the case of local knowledge sharing and transmission in a community in Ethiopia, ethnobiological significance of minor landraces of multipurpose crop will be also discussed.