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A PERSPECTIVE TO ENHANCE INNOVATIVE RESEARCH WITH EMPHASIS ON VARIETAL DIVERSITY AND SUSTAINABLE UTILIZATION OF ENSET (*ENSETE VENTRICOSUM*)

Paul Wilkin[1,]*, Aaron Davis[1], Sebsebe Demissew[2], Tom Etherington[1], Mark Goodwin[3], Pat Heslop-Harrison[3], Trude Schwarzacher[3] and Kathy Willis[1]

ABSTRACT: The current status of enset in cultivation in Ethiopia and its more widely distributed wild populations is reviewed. Biodiversity research gaps are identified, and the potential benefits of the plant and benefits of undertaking that research are discussed, in particular on food and resource security and livelihoods in Ethiopia. Knowledge of the resilience of enset will provide the evidence base underpinning a decision whether to expand its use in Africa.

Key words/phrases: Diversity, Enset, Food security, Livelihoods, Resilience.

INTRODUCTION

Enset (ensete, Ethiopian or Abyssinian banana; *Ensete ventricosum* (Welw.) Cheesman, Musaceae) is a perennial herbaceous plant that can achieve 12 m in height when flowering. It is similar in vegetative form to the related banana and plantain (*Musa x paradisiaca* L.), possessing a false stem and large, paddle-shaped leaves. It is distributed across central, eastern and southern Africa (Lye and Edwards, 1997; e-Monocot, 2016). Despite this widespread distribution in Africa it has only been domesticated in Ethiopia, with hundreds of landraces and farmers' varieties found in diverse climatic and agroecological systems providing multiple ecosystem services (Ehret, 1979; Brandt, 1996; Yemane Tsehaye and Fassil Kebebew, 2006). Unlike banana and plantain that are farmed for their fruit, its swollen stem base and corm provide a long term, year-round and potentially low off-farm input dietary starch source for 20 million people in southern and southwestern Ethiopia. Food is harvested in multiple forms from different parts of the corm and leaf sheaths (Dessalegn Rahmato, 1996).

Enset has a number of important attributes as a crop. Perhaps the most significant is its potential to be a climate-smart crop for the future based upon its apparent ability to withstand long periods of drought (e.g. Quinlan

[1] Royal Botanic Gardens, Kew, Richmond, Surrey TW9 3AB
[2] National Herbarium of Ethiopia, Department of Plant Biology and Biodiversity Management, College of Natural and Computational Sciences, Addis Ababa University, P.O. Box 3434, Addis Ababa, Ethiopia
[3] Department of Genetics, University of Leicester, LE1 7RH UK
*Author to whom all correspondence should be addressed

et al., 2015). The plant can be harvested at any time during the year and at any stage over several years. Enset-derived starchy foods can also be stored for long periods (Mulugeta Diro and Endale Tabogie, 1994; Genet Birmeta, 2004). The crop has been reported to produce the highest yield per unit land area in Ethiopia (Tadesse Kippie, 2001). The carrying capacity of land planted to enset is around 0.2 hectares for a household of seven people, as opposed to 1.5 hectares of land with annual grain; yield from enset therefore has the ability to support a larger population per unit area than regions that grow cereals (Teshome Yirgu, 2016). Enset also supplies fibres, traditional medicines, animal fodder and a food source for bees (Brandt *et al*., 1997). As a perennial crop not requiring frequent soil cultivation and periods of fallowing, enset stabilises soils and microclimates (Tsedeke Abate *et al*., 1996) and is culturally significant (Shigeta, 1997; Tadesse Kippie, 2001). As a result of these attributes, enset farming provides a long-term, sustainable food supply, with minimum off-farm input.

Despite the current importance of enset and its potential to play a more substantial role in resource provision at a broader scale, relatively less is known about its biology compared to other crops in Ethiopia. This includes aspects of its reproductive morphology, pollination and dispersal and the genetic diversity of both wild and cultivated forms. There is also limited understanding of its susceptibility to disease, associated mycorrhizal assemblages and resilience to pests and pathogens. There has been little international research on enset involving scientists from outside Ethiopia. Thus collaborative biodiversity science is needed to fill critical knowledge gaps and thus enable the exploitation of enset diversity as a resilient climate-smart crop of the future. A similar programme has generated significant recent improvements in Cassava performance (e.g. Prochnick *et al*., 2012; Ceballos *et al*., 2012).

SPECIFIC RESEARCH NEEDS

Research in the following areas is suggested to provide the information resources needed to enhance exploitation of enset:

a. *Comprehensive field surveying* in order to provide a complete and unified picture of enset's underground and above ground vegetative morphological traits (agronomic and otherwise) and their variation across Ethiopia, covering both wild populations and the hundreds of cultivated forms (farmers' varieties). These data should be linked to that generated from dedicated climate stations co-located with the field surveys, including rainfall, temperature, humidity, soil water moisture/potential. They also need to be coupled to farmer and farm surveys capturing farmers' knowledge and season-by-season feedback on enset cultivation, market price, crop use, traditional cultural practices, and biodiversity and ecosystem service provision. All such data would need dedicated ground-truthing. It would then be possible to fully determine and assess the environmental suitability of enset variation across the entire Ethiopian enset-growing landscape via bioclimatic modelling using proven, state-of-the-art species distribution model (SDM) methodologies (e.g. Hannemann *et al*., 2015) for producing bioclimatic envelopes and accurate mapping of trait distribution in unmanaged and cultivated environments in Ethiopia using advanced GIS tools. Resilience traits and their locations would be determined, and varieties identified that grow and yield well in challenging environmental conditions. This research would allow comparison with other climate smart crops that are candidates to play a part in improving lives and livelihoods in Africa.

b. *Determination of inflorescence form and function*. Remarkably little is known about the reproductive morphology of enset beyond basic botanical description (e.g. Lye and Edwards, 1997). Cultivated enset is propagated vegetatively and traditionally harvested before or at the point of inflorescence initiation when the corm is at its largest. Hence inflorescence-bearing plants are rarely encountered (Genet Birmeta *et al*., 2004) and gene flow does not occur between farms or from wild to cultivated plants to recombine diversity. Wild enset produces inflorescences on what is thought to be an irregular multi-year cycle, but there is no data on factors stimulating the transition to flowering. Basic data is needed on inflorescence initiation and form, floral morphology, pollination, fruit morphology and development and seed biology. Knowledge of these traits is necessary to underpin successful conventional breeding of this crop and conservation under *in* and *ex situ* approaches (germplasm collections and seed banking). Low levels of genetic diversity resulting from cultivation of a small number of clones potentially reduce resilience to pathogens, at least on a local scale. Hence, there is a need to propagate and improve enset through sexual reproduction. This suggests that investigation of flowering phenology and development, morphology, pollination mechanisms and seed germination biology are required. This should be undertaken via field studies of wild or feral plants, with inflorescence condition being recorded over time including via photography and floral visitor capture (following the methodological principles of Faegri and van der Pijl, 1979; Dafni, 1992) and make dried and ethanol-preserved specimens for later study of morphology and development. The form and colour of the inflorescence suggest moth pollination, indicating the need to employ an infrared video camera in night mode to record nocturnal visitors.

c. *Quantification of the genetic diversity of cultivated and wild enset in Ethiopia*. There have been limited studies of genetic diversity in cultivated enset (e.g. Zerihun Yemataw *et al.*, 2016a) but no comprehensive research at landscape scale. Genomic techniques that have been applied extensively to other crops including the closely related banana are only starting to be deployed for enset (Harrison *et al*., 2014). A comprehensive survey of genetic diversity at population and landscape scale across enset growing regions of Ethiopia is required, as advocated in e.g. Poland and Rife (2012). Such a survey should include whole genome and targeted sequencing and comparison with the latest banana genome assembly (Droc *et al*., 2013). Analysis of earth observation data from satellites, typically 30 x 30 m resolution or better, would need to be tested and trained to see if the crop can be measured in the field, discriminated from bananas, and growth stage or potential yield estimated. It would also require genotyping by sequencing strategies, including levels of heterozygosity and population genetic structures and identification by comparison with *Musa* and other reference genomes of genes relating to developmental processes of flowering, fruiting, starch biosynthesis and storage, and disease resistance. Ultimately, this research would lead to molecular markers and selection criteria for identifying pre-breeding lines.

d. *Surveying ploidy* across the distribution of enset to test the hypotheses that only diploids exist in the wild and cultivated populations (Genet Birmeta *et al*., 2004). Mapping ploidy would enable its potential link to resilience (e.g. Henry and Nevo, 2014) to be evaluated.

e. *Determining the resilience of cultivated enset to pests and pathogens*. There has been some research on bacterial wilt caused *Xanthomonas campestris* pv. *musacearum*) (e.g. Tariku Hunduma *et al*., 2015; Zerihun Yemataw *et al*., 2016b). The role of mole rats as agricultural pests of enset is also recorded (Earecho, 2015). However, the importance of pathogenic fungi and viruses and other key pests of tuberous crops such as nematodes is significantly under-recorded (see e.g. Blomme *et al*., 2013). This knowledge gap needs to be addressed both via field surveys and farmer interviews and inventory and investigation at genetic level. These data will determine patterns and intensity of occurrence and test the effect of existing management practices (which need to be documented) so that potential impacts from pests and pathogens can be included within enset distribution suitability models. Stress resistance genes should be sought and characterized from unimpacted populations and varieties within outbreak areas, and disease resistant forms conserved in germplasm collections.

f. *Relationships with mycorrhizal fungi and other soil organisms*. The microbiome has been shown to influence plant performance and is important for growth and development, nutrient acquisition, tolerance to biotic and abiotic stresses, for protection against pathogens and to sustain soil quality. Knowing how the phytobiome networks is an essential tool for acrosystem breeding, and should be considered as an additional factor in plant breeding programmes (e.g. Berg *et al*., 2014; Bulgarelli *et al*., 2013). Therefore, investigations into the phytobiome using an environmental sequencing approach are required to assess its relationship with resilience and its potential importance to enset breeding.

POTENTIAL BENEFITS AND BENEFICIARIES

The drivers underlying research on enset are the human and environmental challenges facing Ethiopia and Africa as a whole as the 21st century unfolds. Chief among them is provision of sufficient food to the continent's population as it doubles in size by 2050 (based on the latest UN Department of Economic and Social Affairs figures) against a backdrop of a changing climate with a projected increase in frequency of droughts. Ethiopia's population is predicted to rise from an estimated 100 M in 2016 to 240 M in 2100. Multiple solutions will be needed, including diverse, resilient, productive crops like enset that can help to increase local production and reduce supply chain lengths and need for imports. The same arguments also apply to the other provisioning, regulating, supporting and cultural services currently or potentially supplied by enset, including energy, animal fodder and medicine production for a rapidly growing population.

Not only will Africa's population increase faster than any other part of the globe, it will also undergo unprecedented urbanization. Fifty percent of the population of Africa will be urbanized by 2050. The population of Addis Ababa has been predicted to increase from an estimated 3.4 M in 2016 to 35.8 M in 2100. Enset starch products can be stored and improve their flavour through storage, making them particularly suitable for urban food supply in comparison with other tuber crops in which storage and transport are major disincentives to use. Recently, evidence has begun to emerge of new value chain networks for enset, with urban Ethiopians acquiring a renewed interest in enset products as elements of their national cuisine

(Geda, 2009).

All of the challenges around ecosystem service provision in Africa and Ethiopia have to be met under the impact of climate change. It has been widely reported, based on current modelling-derived evidence from the IPCC that Africa will be among the most impacted areas of the planet. The research ideas outlined here will place policymakers on the path to knowing where, when and how enset could help to provide for Ethiopia and Africa's future. Enset has the potential to help many other African nations, particularly those in eastern, southern and central Africa where it is native and climatic regimes are similar to that of Ethiopia, via provision of food, bioenergy and other ecosystem services.

CONCLUSION

The research suggested has the potential to improve the understanding of resource security and supply of enset. The genotypic and phenotypic resources developed would form the basis of subsequent research that would be focused on breeding novel, resilient, high yielding varieties geared to local conditions in Ethiopia and the evidence to support a decision on whether to expand its cultivation in Africa.

Without research that leads to understanding of its diversity and ecology, this diverse, Ethiopia-specific, culturally embedded orphan crop with ingenious/original cultivation practices is likely to continue to decline relative to minimally diverse introduced crops that are potentially less resilient and provide fewer ecosystem services. A modern science-based inventiveness, mainly guided by adaptation to climate change and response to population pressures and food security drives may be the minimum required to revolutionize and transform enset cultivation in Ethiopia. Promotion of resilience within enset will enhance its role in all future resource provision. Making available enset's full variation to farmers will reduce inputs (including labour, agrochemicals and water) and increase outputs (including reduction in both field and post-harvest losses). This will in turn impact livelihoods and economic development at local, regional and national scale.

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