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Review article – Thematic Issue

Traditional enset [*Ensete ventricosum* (Welw.) Cheesman] sucker propagation methods and opportunities for crop improvement

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Summary

Introduction – **This review focuses on the enset seed systems in Ethiopia and explores opportunities to improve the system. Cultivated enset is predominantly vegetatively propagated by farmers. Reproduction of an enset plant from seed is seldom practiced by farmers and has been reported only from the highlands of Gardula. Seedlings arising from seed are reported to be less vigorous than the suckers obtained through vegetative propagation. Rhizomes from immature plants, between 2 and 6 years old, are preferred for the production of suckers. The average number of suckers produced per rhizome ranges from 40 to 200, depending on soil conditions, cultivar type, size and age of the parent plant, amount of rainfall, land preparation and time of planting. Traditional macro-propagation of enset suckers involves both men and women farmers. Sucker propagation and transplanting activities often contribute to the dissemination or maintenance of pests (*e.g.*, the enset root mealy bug or nematodes) and diseases (*e.g.*, enset bacterial wilt).** *Conclusion* – **Macro- and micro-propagation are useful technologies to improve the efficiency of sucker production and to provide clean replacement plants in locations where diseases have affected plantations or to locally multiply newly introduced cultivars for distribution.**

Keywords
enset, Ethiopia, macro-propagation, micro-propagation, vegetative propagation

Résumé

Méthodes de propagation des rejets d'ensète traditionnel [*Ensete ventricosum* (Welw.) Cheesman] et opportunités pour l'amélioration culturale.

Introduction – **Cette revue se concentre sur les systèmes semenciers de l'ensète en Ethiopie et explore les opportunités pour améliorer le système. L'ensète cultivée est principalement multipliée par voie végétative par les agriculteurs. La reproduction d'un plant d'ensète à partir d'une graine est rarement pratiquée par les producteurs et n'a été signalée que sur les hauts plateaux de Gardula. Les plantules issues de semences seraient moins vigoureuses que les rejets obtenus par multiplication végétative. Les rhizomes de plantes immatures, âgées de 2 à 6 ans, sont préférés pour la production de rejets. Le nombre moyen de rejets produits par rhizome varie de 40 à 200, en fonction du type de sol et de cultivar, de la taille et de l'âge de la plante mère, de la pluviométrie, de la préparation du sol et de la saison de plantation. La macro-propagation traditionnelle des rejets d'ensète mobilise les agriculteurs, hommes et femmes. Les activités de propagation et de repiquage des rejets contribuent souvent à la dissémination ou au maintien d'organismes nuisibles (par exemple, la punaise cornéenne ou les nématodes) et de maladies (par exemple, le flétrissement bactérien de l'ensète).** *Conclusion* – **La macro- et la micro-propagation sont des technologies utiles pour améliorer l'efficacité de la production de rejets, et pour fournir des plants sains de remplacement aux endroits où les maladies ont affecté les plantations ou pour multiplier localement des cultivars nouvellement introduits.**

Mots-clés
ensète, *Ensete ventricosum*, Ethiopie, macro-propagation, micro-propagation, multiplication végétative

Significance of this study

What is already known on this subject?

- Traditional macro-propagation methods, using entire rhizomes or rhizome pieces, currently suffice to provide the needed enset suckers at farm, village or landscape level.

What are the new findings?

- When larger quantities of suckers are needed, *e.g.*, when introducing a new enset cultivar or coping with severe disease or pest impacts, improved/novel micro- and macro-propagation techniques, as listed in this review paper, could offer solutions.

What is the expected impact on horticulture?

- Clean enset planting materials as part of an integrated field and landscape management approach will contribute to healthier and more resilient systems.

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Introduction

The arable Ethiopian highlands, ranging from 1,200 to 3,100 m a.s.l., and located between 35°17'23.56" and 40°23'24.35"E and 5°18'22.38" and 14°09'47.70"N, are considered as one of the foremost centres of origin for the domestication of a wide variety of plants, including wheat (*Triticum*), barley (*Hordeum vulgare*), coffee (*Coffea*), various pulses, tef (*Eragrostis tef*) and enset (*Ensete ventricosum*) (Vavilov, 1926; Brandt, 1996; Haile *et al.*, 1996). The domestication of enset is estimated to have arisen in Ethiopia as early as 10,000 years ago (Brandt *et al.*, 1997). As a genus in the *Musaceae* family, enset shares many botanical characteristics with its close relative, the banana. The wild and cultivated *Ensete ventricosum* is a large, tree-like monocot, with stiff, semi-erect leaves and a flower that resembles that of banana, but which produces no edible fruit.

As with wild enset, cultivated enset often produces seed. However, cultivated enset is predominantly propagated vegetatively. Traditional vegetative macro-propagation methods can rapidly multiply large quantities of planting materials and are sustainable in the absence of pests (*e.g.*, the enset root mealy bug) or diseases (*e.g.*, Xanthomonas wilt of enset). However, when pest/disease-affected plants are present in a field, it becomes more difficult to produce healthy planting material using traditional propagation methods. This makes enset farming systems vulnerable, particularly in the context of biotic factors and climate change/higher temperatures that could worsen the situation (Brandt *et al.*, 1997; McKnight, 2013).

Propagation by seed is possible, but for reasons of regular food scarcity, family or social obligations and annual ceremonies, and an often limited number of enset plants per farm, households most often harvest enset before the plant reaches full maturity and a bunch/fruits with seeds is developed (Pankhurst, 1996). In addition, enset plants should preferably be harvested at or immediately after flower emergence to produce optimum quantities and quality of *kocho* (*i.e.*, fermented starch obtained from grated rhizome, real stem and pseudostem leaf sheath tissue) (Tsegaye and Struik, 2002; Yemataw *et al.*, 2014). At the farm-level, propagation of enset cultivars is primarily vegetative, through the production of suckers.

In a typical enset farm, the main activities include preparing and planting rhizomes for sucker production, production of young suckers (Figure 1), subsequent one or more steps of transplanting of the suckers (*i.e.*, plants are uprooted, most of the roots and leaves are removed and plants are replanted at a wider spacing), final transplanting, management of the mature enset plot, harvesting plants, processing of pseudostem leaf sheaths and rhizomes, and fermentation and storage of *kocho*/starch. This review focuses on the enset sucker propagation methods/system (*i.e.*, all steps before the first transplanting) and opportunities to improve the system. This review is based on publications, grey literature and reports which were compiled by the Southern Agricultural Research Institute (SARI) and Bioversity International. Various aspects of enset propagation have been researched on over the past decades, and this review provides a structured overview of results and recommendations, and discusses research knowledge gaps in the light of possible future research endeavours.

FIGURE 1. Traditional macro-propagation of enset seedlings in a backyard in southern Ethiopia (Source: Guy Blomme).

Propagation by seed

Wild enset reproduces through seed, while cultivated landraces are vegetatively multiplied, which over centuries of cultivation might have altered seed morphology (Zerihun Yemataw, 2017, pers. commun.). Enset seeds from cultivated types are characterized by low germination rates (Negash, 2001). This is attributed partly to the structure of the seed coat, which is hard, impermeable and contains certain chemical inhibitors which affect germination efficiency, and partly due to the considerable number of so-called empty seeds, which are seeds containing no embryo or endosperm (Negash, 2001). In contrast, seeds from wild enset types often have a far higher germination rate, as has been observed in Ethiopia and along the rift valley highlands in eastern Democratic Republic of Congo (Zerihun Yemataw, 2016, pers. commun.; Guy Blomme, 2014, pers. commun.). Karlsson *et al.* (2013) found that germination of mature enset seeds obtained from five wild and six cultivated enset plants ranged from 5–55% depending on genotype. In this study, the average germination rate did not differ significantly between seed lots of wild and cultivated origin, which might be due to the used landraces and wild genotypes. Overall, time to 50% of final germination was 8.5 weeks and no germination occurred after 28 weeks of incubation. Dalbato *et al.* (2014) did not find a positive effect of chemicals, mechanical scarification, or warm water pre-treatments on germination. In contrast, Diro and Tsegaye (2012) reported an improved germination rate after scarification, which may be linked to the assessed enset landraces.

Reproduction of the enset plant from seed is seldom practiced by farmers (as plants are most often harvested before/at flower emergence in order to obtain maximum amounts of starch). Harvesting at flower emergence prevents relocation of nutrients from rhizome and stem to the growing inflorescence. Reproduction via seed has only been reported from the highlands of Gardula, which might indicate an interest from the farmers to compare vegetative propagated landraces with seedlings obtained from seed (which represent new genotypes). However, seedlings obtained from seed are less vigorous in terms of speed of growth than the suckers obtained from vegetative propagations (Alemu and Sandford, 1991).

The difficulty propagating enset from seeds has been a limiting factor for enset breeding efforts (Morpurgo *et al.*, 1996; Zerihun Yemataw, 2017, pers. commun.). The Ethiopian national research organization (SARI) at its Areka research station, initiated enset breeding efforts in 1999 through the collection of landraces and wild genotypes as parent materials, with the aim to breed improved enset genotypes for various use values (*e.g.*, *kocho*, *bulla*, fiber and *amicho*).

Traditional vegetative propagation

Vegetative propagation is the primary method used by farmers to produce enset suckers. Enset has a large underground stem (*i.e.*, rhizome, also called a corm), with nodes and internodes. Suckers arise on the rhizome surface. The growing buds are not located on the outer surface of the rhizome as 'eyes' but are found in concentric circles on the upper sections of the rhizome, and around the apical meristem, and can be revealed though removal of leaf sheaths layer by layer from the rhizome (Diro *et al.*, 1996). In contrast to banana, naturally occurring sucker production of field-grown enset plants is rare due to the dominance of the apical meristem, which must be destroyed/removed in order to stimulate sucker production. When the apical meristem is left intact, only one shoot will arise (Diro *et al.*, 1996).

Rhizomes from immature vegetative stage plants, between 2 and 4 years old, are preferred for the production of suckers (Bezuneh and Feleke, 1966; Negash, 2001; Yemataw *et al.*, 2014). The apical meristem is slightly raised/grows upward within the pseudostem (3–12 cm for 2–3 year old plants) and therefore a portion of the pseudostem (10–20 cm) must remain intact when harvesting a rhizome for sucker production. This is in order not to remove large sections of tissues situated around the apical meristem, tissues that can give rise to numerous suckers (Diro *et al.*, 1996). After uprooting the rhizome (sometimes it is left in the ground), the apical meristem and ideally as little as possible of the surrounding tissues is removed, making the center of the pseudostem hollow (Negash, 2001). The hollow area is refilled with manure, soil, humus and perhaps soft crushed stones (Simmonds, 1958; Bezuneh and Feleke, 1966; Olmstead, 1974) or the rhizome is split into two or four equal parts. The rhizome may be left in the sun or shade for 2–5 days before planting to allow the wounds to heal (Tsegaye and Struik, 2002; Bezuneh and Feleke, 1966). Rhizomes or rhizome pieces are planted (20–30 cm deep) in loosened soil, often mixed with manure (Diro and Tsegaye, 2012).

Field trials demonstrate that the practice of filling the hollow space with clod or manure has no significant effect on sucker production; nor does the practice of leaving a rhizome in the sun for a few days before re-planting (Diro *et al.*, 1996; Makiso, 1996). Replicated field trials have also shown that suckers from half and quarter split-rhizomes emerged earlier than those from the whole rhizome (Tabogie and Diro, 1992). On average 22, 76 and 102 suckers emerged from whole, half and quarter rhizomes, respectively (Tabogie and Diro, 1992). These observations might indicate that apical dominance of the central meristem is not the only factor involved in suppressing suckers/regulating sucker development on enset rhizomes. Early emergence is associated with more vigorous suckers, which promotes success of establishment, higher and earlier yield. Moreover, failure of suckers to fully develop is higher in the case of whole rhizome (25%) and lowest for the half rhizome (8%) (Tabogie and Diro, 1992). Farmers in the Gurage and Wolaita areas are known to sort undersized/underdeveloped suckers (*i.e.*, suckers that are not growing vigorously enough) and replant them in the nursery for further growth, and eventual field planting (Spring, 1996).

Variations in rhizome preparation are reported between different ethnic groups (Diro *et al.*, 1996). The ethnic affiliation is a stronger determinant for decision-making than the wealth category to which the farming household belongs (Tsegaye and Struik, 2002). Differences are seen in whether or not farmers uproot the rhizome, and whether or not it is split after uprooting (Diro *et al.*, 1996). For example, farmers of the Wolaita, the Gamo and the Gofa use a split rhizome to produce suckers. Farmers from other areas prefer the whole rhizome. Where whole corms are used, farmers either destroy the apical meristem, but leave the rhizome *in situ* (Jemjem, Gedeo and some areas of Gofa awrajas), or they first uproot the rhizome, destroy the apical meristem and then replant the rhizome (Kambata-Hadiya and Chebo-Gurage areas). Farmers from the Sidama area and the Ari either use split rhizome or whole rhizome preparation methods to produce suckers (Diro *et al.*, 1996; Yntiso, 1996; Tsegaye and Struik, 2002).

Karlsson *et al.* (2014) assessed the effect of rhizome splitting, application of cow manure just next to buried rhizomes and regular watering on sucker emergence and growth. The first suckers started emerging at 50 days after rhizome burial. Time to sucker emergence was longer for entire than for split rhizomes, while a higher number of suckers were obtained per rhizome when it was split. Less than 60 suckers were recorded for entire rhizomes, while between 60 and 140 suckers were most often recorded per rhizome for the rhizomes that were split in two or four pieces. Watering decreased average time to sucker appearance and resulted in more even sucker emergence and growth. For example, time to sucker emergence ranged from 60 to 65 days for watered rhizomes of the 'Zerita' enset cultivar, while it ranged from 60 to 85 days for non-watered rhizomes. This is contradictory to local belief which often says that it is impossible to water newly buried rhizomes, as this practice will cause rhizome rotting. In areas where extended droughts are common and watering is impossible, it may be preferable to bury entire rhizomes, to, as much as possible, utilize the rhizome's own water. Blomme *et al.* (2008) reported that enset rhizomes contain 83% water, while rhizomes used for propagation (sourced from 2 to 4 years old plants) weigh on average around 2–4 kg. The application of cow manure adjacent to rhizomes, to give the emerging suckers quick access to nutrients, resulted in a high sucker emergence rate and subsequent vigorous growth. Karlsson *et al.* (2014) concluded that vegetative propagation using buried disease-free rhizomes in the field results in a large amount of healthy and vigorous suckers, ideal for re-planting, 9 months after burial.

Tsegaye and Struik (2002) reported that suckers appear 2–3 months after the rhizome or rhizome pieces have been buried and remain undisturbed for at least a year before the first transplant is carried out. Diro *et al.* (1996) observed that new roots initiate from growing points on the suckers' developing rhizome after transplanting. From 2 to 6 new roots of 1.5 to 19 cm length can be expected 15 days after transplanting (DAT) and about 50 cm at 35 DAT. Leaves desiccate following transplanting, except for the central cigar leaf, which continues to grow up to 15 DAT. For ease of handling, farmers may remove roots and leaves upon transplanting since their absence does not affect the growth of the transplants (Diro *et al.*, 1996).

The number of suckers produced per rhizome ranges between 40 and 200, depending on soil conditions, cultivar type, size and age of mother plant rhizome, amount of rainfall, land preparation and time of planting (Shambulo *et al.*, 2012). An average enset farming household cultivates between 200 and 400 plants and consumes about 10 to 20 plants annually. So, 1 to 4 parent rhizomes can fulfil the annual requirement for enset planting materials (Bezuneh and Feleke, 1966; Negash, 2001).

Overall, traditional propagation of enset suckers is resource intensive, in terms of space and labour requirement. For example, Makiso (1976, cited in Hiebsch, 1996) noted that in a typical entire 8-year enset production system, with 4 transplanting steps, with each step taking respectively 1, 1, 2 and 4 years, an overall surface area of 2,455 m^2 is needed to harvest 80 nearly mature enset plants from a space of 500 m^2 annually. This production system starts with a 5 m^2 nursery with 5 rhizomes (at 1 × 1 m spacing), planted at year 0. After one year (year 1), the ±100 suckers produced in this nursery are transplanted for the first time to a 50 m^2 field (at 1.0 × 0.5 m spacing). After another year (year 2), the ±89 surviving plants are transplanted for a second time to one of two 200 m^2 fields (at 1.5 × 1.5 m spacing). Two years later (year 4), the ±80 surviving plants are transplanted for the third time to one of four 500 m^2 fields (at 2.5 × 2.5 m spacing). The plants are now left to mature for 4 years (year 8) until harvest, and every year, one of these four final fields, consisting of 80 plants, can be harvested. This system takes 8 years to become productive, after which harvesting can be carried out annually. The number of plants in Makiso's (1976) example is based on the observation that 30–100 enset plants harvested annually supplies the enset needs for a 5–6 person household. The example also assumes a 10% loss of plants at each transplanting phase.

Enset cultivar diversity and sucker production

Throughout the enset-growing regions, the maintenance of enset cultivar diversity contributes significantly to food and livelihood security, whereby wealthier households tend to have more land, grow more enset and maintain more diversified cultivars (Negash, 2001). Farmers base their choice of cultivar on multiple criteria including ecological adaptation, tolerance to various diseases, rate of growth and maturity, fibre quality and quantity, quality and quantity of food yield, ease of work during decortication, size and taste of rhizome after cooking, food and fodder quality, medicinal attributes (Makiso, 1996; Negash, 2001; Tsegaye and Struik, 2002; Yemataw *et al.*, 2014).

A loss of cultivar diversity has been reported due to disease encroachment (Negash, 2001). Propagation and transplanting activities may aggravate the dissemination and maintenance of certain pests and diseases, such as bacterial wilt caused by *Xanthomonas campestris* pv. *musacearum*, the enset root mealy bug (*Cataenococcus ensete*), the root lesion nematode *Pratylenchus goodeyi*, the root-knot nematode *Meloidogyne* sp., mosaic and chlorotic streak viruses (Quimio and Tessera, 1996; Morpurgo *et al.*, 1996; Negash, 2001).

Effects of gender in enset sucker production

The production of suckers consists of a series of consecutive tasks, whereby some are more gender-specific than others. As a backyard crop, enset is primarily considered a women's crop (Negash, 2001; Pankhurst, 1996). However, decision-making regarding cultivar diversity is shared between husband and wife, as is the time of planting (Negash, 2001). Women are more involved in carrying suckers for transplanting and manuring the transplants, and also contribute with plant harvesting, leaf sheath and rhizome processing, *kocho* storage and marketing. Whereas men are more involved in propagation, transplanting, digging the pits (for fermentation of the harvested enset), and weeding. There is some flexibility in gender-division, with males helping during harvest and females responsible for transporting manure from the homestead to the field and for weeding (Olmstead, 1974).

Sucker movement and markets

There are very few reports describing sucker markets and movement of enset suckers. In Kaffa Shaka, enset suckers of various cultivars are traditionally exchanged together with indigenous knowledge about the crop/cultivars as a means of increasing cultivar diversity on farm. Exchanges are made between neighbours, relatives or kin and within communities, between neighbouring villages and sometimes beyond (Negash, 2001). Rahmato (1996) reports that poor farmers may occasionally sell their young plants to others who need them for propagation purposes. Woldetensaye (1997) reported that farmers from Dale Yirgalem district (located higher than 2,100 m in the Sidama zone of the Southern Nations, Nationalities, and Peoples' Region of Ethiopia) produce suckers as a main source of cash income and sucker markets are widely practiced. However, selling and buying of suckers in Sodo and Butajera districts hardly occurs, as planting material is mainly distributed as gifts. In addition, households in these districts are most often self-sufficient for sucker production.

Improved/novel rapid propagation technologies

Several novel methods for rapid propagation of enset are found in the literature. Alternative pathways for the rapid propagation of enset are discussed extensively by Diro and Van Staden (2004), including zygotic embryo culture (Bezuneh, 1980; Negash *et al.*, 2000, 2001; Diro and Van Staden, 2003), shoot tip culture (George and Sherrington, 1984; Nehra and Kartha, 1994; Afza *et al.*, 1996; Morpurgo *et al.*, 1996; Zeweldu, 1997; Negash *et al.*, 2000), and callus culture and somatic embryogenesis (George and Sherrington, 1984; Zeweldu, 1997; Afza *et al.*, 1996; Morpurgo *et al.*, 1996; Mathew *et al.*, 2000; Mathew and Philip, 2003).

Macro-propagation and micro-propagation (syn. tissue culture or *in vitro*) are useful technologies to provide large numbers of replacement plants where diseases have reduced plantations or to locally multiply desired cultivars for distribution. Makiso (1996) refers to a macro-propagation method to regenerate enset plants by cutting the rhizome, with leaf bases intact, vertically into small pieces and planting in plastic tubes or bags, and raising them in a growth chamber with proper temperature and humidity (20 °C and moist medium of soil or any other material).

These technologies may also help reduce the vulnerability of enset farming systems in several ways. Firstly, in combination with a field gene bank collection, the use of improved micro-propagation (syn. tissue culture or *in vitro* culture) enables conservation, rapid propagation and distribution of clean planting materials (Negash, 2001). Although no off-types have been reported, a challenge with multiplying enset in vitro is the presence of phenolic compounds which result in extensive blackening, especially at the stage of bringing meristems from field-grown plants into culture (Disasa and Diro, 2012). Diro and Van Staden (2004) also note that micro-propagation of enset plants is prone to various problems, including extensive blackening as a result of phenolic oxidation of explants, necrosis and the formation of unwanted callus. Furthermore, low levels of multiple shoot formation are observed from shoot tip explants, for which the use of cytokinins does not provide a solution (Diro and Van Staden, 2004). Secondly, improved micro-propagation facilitates the use of rapid screening of enset cultivars for tolerance or resistance to pests and pathogens, as in the case of banana (*e.g.*, Dochez *et al.*, 2000; Tripathi *et al.*, 2008). Thirdly, enset breeding may profit from improved micro-propagation through somatic hybridization and recombinant DNA techniques applied to callus culture to obtain new genotypes, or by facilitating seed germination (Diro and Van Staden, 2004).

Conclusion

Traditional macro-propagation methods, using entire rhizomes or rhizome pieces, currently suffice to provide the needed enset suckers at farm, village or landscape level. However, when larger quantities of suckers are needed, *e.g.*, when introducing a new enset cultivar or coping with severe disease or pest impacts, improved/novel micro- and macro-propagation techniques, as listed in this review paper, could offer solutions. Current research in Ethiopia on fine-tuning *in vitro* multiplication technologies and ongoing breeding efforts for improved enset genotypes for various use values will contribute to a high-quality clean planting material supply system.

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