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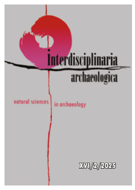

Crop of the Future: A Focus on Enset (*Ensete ventricosum* (Welw.) Cheesman), from Past to Present

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ABSTRACT

Enset (*Ensete ventricosum* (Welw.) Cheesman) is an important plant belonging to the Musaceae family, cultivated predominantly in south and south-west Ethiopia. It is often referred to as the "tree against hunger" and considered a good crop to tackle food insecurity. Yet, it remains a relatively unknown crop outside its country of origin. Our interdisciplinary project "*Evolutionary dynamics of vegetative agriculture in the Ethiopian Highlands: integrating archaeobotanical and genomic science*" aims to provide a better understanding of the evolutionary and cultural history of enset by unravelling the narrative of the cultural and geographical "story" of domestication and its antiquity. Archaeobotanical investigations, specifically phytolith analysis, are crucial to estimate the antiquity of the enset cultivation system and to do this, robust phytolith identification criteria need to be established. Results on the on-going phytolith analysis are presented, particularly looking at the phytoliths found in enset leaves. We focus on the variations of enset phytoliths and where these are in the plant. We also introduce the aims of, and some preliminary data from, our ethnographic work in south-west Ethiopia which investigates the extent to which agricultural and cultural changes in recent decades have altered patterns of local enset landrace diversity, uses and relative importance.

1. Introduction

With predictions of worsening environmental conditions due to climate change, food security is an increasingly important topic (Morrow *et al.*, 2023). To tackle food insecurity, some crops have been flagged as potential future buffers. One of these crops is enset (*Ensete ventricosum* (Welw.) Cheesman), an herbaceous monocarpic plant, often referred to as the "tree against hunger" (Brandt *et al.*, 1997). It is a rich source of carbohydrates, making it an important staple crop for at least 20 million people in Ethiopia (Jacobsen *et al.*, 2018). At present, its cultivation is highly localised in southern, south-western and central Ethiopia and as such it remains under-researched. Yet enset has been considered as one of the reasons why populations reliant on enset farming managed to survive the famines during the 1970s and the 1980s (Aneseyee *et al.*, 2022; Yemataw *et al.*, 2014).

Enset belongs to the banana family Musaceae and it is also known as the false banana. The entire enset plant is used for culinary, construction and craft purposes, except for the inflorescence and infructescence. Cultivated enset is clonally cultivated from the corm of an immature plant (3–4-year-old plant; Tsegaye and Struik, 2002) whereas in the wild, enset is seed dispersed mainly by rodents and primates (Figure 1).

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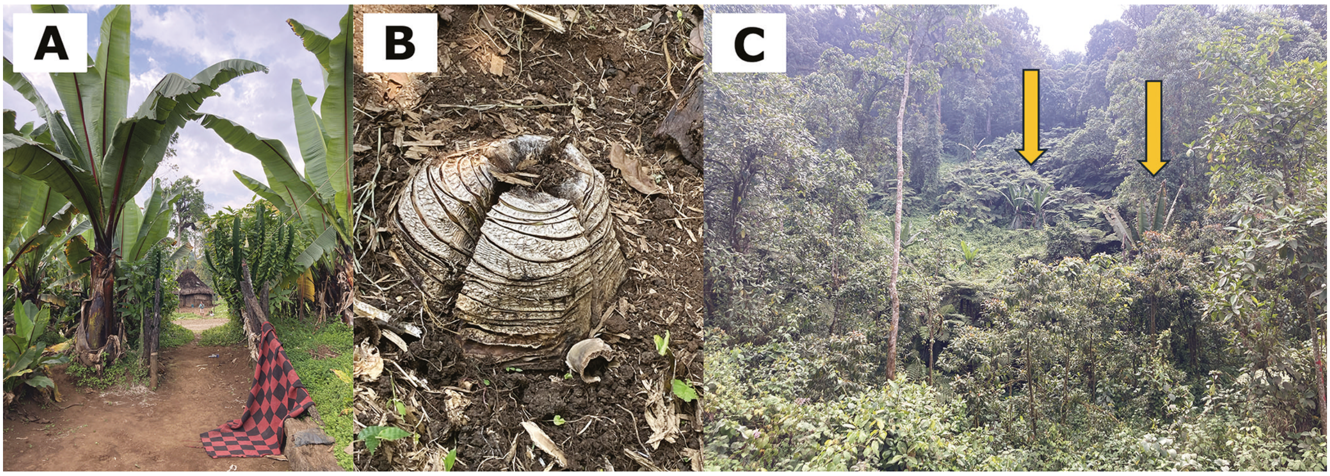


Figure 1. A: Image of domesticated enset in a home garden in Yeki, Sheka, Ethiopia; B: Corm used for vegetative propagation divided into quarters and left to dry for a month in Bench Sheko, Ethiopia; C: Wild enset indicated by the arrows in the Afromontane Forest in Yeki, Sheka, Ethiopia.

Hildebrand (2003) reports a decline in seed production and maturation between wild and domesticated enset. Most domesticated enset, however, is not allowed to mature to the point of fruit production and leave no trace of seeds, so seeds are not expected to be archaeologically informative in contexts where the pseudostems are harvested for starch. It is for this reason that to identify enset in archaeological deposits, one needs to turn to phytolith analysis. Musaceae plants are known to produce diagnostic Volcaniform phytoliths in the leaves although most research has focused on the *Musa* genus rather than on *Ensete* (Piperno, 2006; Tomlinson, 1959).

Our project "*Evolutionary dynamics of vegetative agriculture in the Ethiopian Highlands: integrating archaeobotanical and genomic science"* centres on the origins of agriculture in Ethiopia, focusing on the vegetatively propagated crop enset by linking archaeological, ethnobotanical and genomic datasets. The research addresses questions on the evolutionary and cultural history of enset and by doing so, hopes to have a better understanding of how agricultural systems and human demography co-evolved and how contemporary diversity patterns formed. The aim is to unravel the narrative of enset by establishing the cultural, genetic and geographical "story" of domestication and its antiquity. A major objective is to test whether landrace patterning primarily evolved through environmental adaptation, cultural practices and preferences, or the antiquity of exploitation. By combining datasets from different disciplines, the project brings together multiple time depths to link the past to the present. In this paper we present partial results derived from the archaeological and ethnographic work of our project.

The ethnobotanical work investigates how enset is used, its relative importance and changes in living memory. The farmer interviews are important for investigating the extent to which agricultural, socio-economic, cultural or environmental changes in recent decades have altered patterns of local enset landrace diversity. Accounting for these changes will help us distinguish the influence of recent agricultural and cultural changes on current diversity patterns from long-term historical patterns.

To test the time depth of cultivation, phytolith analysis is needed to estimate the antiquity of the enset cultivation system. So far, there is no evidence of enset in the archaeological record and this is partly due to a lack of robust phytolith identification criteria and the limited amount of phytolith analysis from archaeological contexts carried out in the region. In this project, we are conducting work on modern reference material with the aim of documenting phytolith morphotypes of enset, and distinguishing between wild and domesticated enset, but also between cultivars and from *Musa*. Once the reference material is refined, a future step will be to look for long-term evidence for enset in agriculture in key archaeological sequences, such as those excavated in the Keffa and Wolaita regions in Ethiopia (*e.g.* Hildebrand *et al.*, 2010; Brandt *et al.*, 2023).

In this paper, we introduce enset by outlining its historical, environmental and cultural background. We then present some of our results from the on-going phytolith analysis, particularly looking at the phytolith morphotypes found in domesticated enset plant parts. Finally, we introduce the aims of, and some preliminary findings from, our ethnographic work in south-west Ethiopia.

2. Enset and agricultural origins in Ethiopia

Ethiopia is an area of high agrobiodiversity (in terms of varietal diversity) for both its endemic (*e.g.* t'ef [*Eragrostis tef* (Zuccagni) Trotter], noog *Guizotia abyssinica* (L.f.) Cass. and enset; Table 1) and long introduced crops (*e.g.* tetraploid wheats (*Triticum* spp.), barley (*Hordeum vulgare* L.), and sorghum (*Sorghum bicolor* (L.) Moench)). Ethiopia was the only African country included in the first map drawn up by the Russian botanist Nikolai Vavilov (1926) illustrating centres of domestication. Although Ethiopia is a major centre of domestication many of its endemic crops remain relatively unknown outside Ethiopia.

Table 1. Crops of the Ethiopian highlands: starch, bean and oil crops.

Crop	Common name	Elevational range (masl)	Native, origins zone	Introduced, origins centre	Main use category
Ensete ventricosum (Welw.) Cheesman	Enset	1000–3100	Southwest		Starch, tuber/pith
Amorphophallus abyssinicus (A.Rich.) N.E.Br.	“Abatcha”, “zize”, “Saganeida” [Konso]	1200–2000	Southwest		Starch, tuber
Arisaema schimperianum Schott	“Koltso” [Gamo]	1800–3600	Southwest		Starch, tuber
Coccinia abyssinica (Lam.) Cogn.	“anchote”	1300–2300	Southwest		Starch, tuber
Coleus maculosus ssp. *edulis* (Vatke) A.J.Paton	Galla potato, “oromo dinch”, “wolayta dinch”	1600–3100	Southwest		Starch, tuber
Coleus rotundifolius (Poir.) A.Chev. & Perrot	Hausa potato, Chinese potato	As above(?)		South India(?), East Africa(?)	Starch, tuber
Colocasia esculenta (L.) Schott	Taro, “garabo”, “godarre”, “longa”[Konso]	1–2100		Southeast Asia	Starch, tuber
Dioscorea alata L.	Greater yam, “kota hari”, “kachi” [Sheko]	1100–2200		Southeast Asia	Starch, tuber
Dioscorea bulbifera L.	Aerial Yam, “boyye”, “Ama” [Sheko], “Oake” [Bench]	1–2000	Southwest		Starch, tuber
Dioscorea cayenensis Lam.	African Yam, “wocino”, “boyye”, “kachi” [Sheko], “hidana” [Konso]	1–2000	Southwest (lowlands)		Starch, tuber
Dioscorea abyssinica Hochst. ex Kunth	African Yam, “wocino”, “boyye”, “kachi”	1–2000	Southwest (lowlands)		Starch, tuber
Manihot esculenta Crantz.	Mitsa Boyiiya / Pampa (Dawro)	450–1600		Southwest Brazil	Starch, tuber
Sauromatum venosum (Aiton) Kunth (*syn. S. nubicum* Schott)	“hamassérau”, “Pansala” [Konso]	1200–2000	Southwest		Starch, tuber
Solanum tuberosum L.	Potato, “tinassa” [Konso]	3000–3500		South America: Andes	Starch, tuber
Avena abyssinica Hochst.	Ethiopian oat, “senar”	2200–28001	North		Starch: cereal
Eleusine coracana (L.) Gaertn.	Finger millet, “dagussa”	500–2000	North(?)	East African mountains(?)	Starch: cereal
Eragrostis tef (Zuccagni) Trotter	Teff, “t’ef”	1500–2400	North		Starch: cereal
Hordeum vulgare L.	Barley, “gebs”	1600–4000		West Asia	Starch: cereal
Pennisetum glaucum (L.) R.Br. (= *Cenchrus americanus* (L.) Morrone in POWO)	Pearl millet, “bultuk”	1–1500		Western Sahel	Starch: cereal
Sorghum bicolor (L.) Moench	Sorghum, “mashila”, “zengada”	1–2400		Eastern Sudan	Starch: cereal
Triticum spp.	Wheats, “adja” (hulled), “sindi” (naked)	1600–2500		West Asia	Starch: cereal
Cajanus cajan (L.) Huth	Pigeonpea, Congo pea, “yewof-ater”	1700–1900 (Konso)		India	Pulse
Cicer arietinum L.	Chickpea, “shimbira”	1750–2600		West Asia	Pulse
Lablab purpureus (L.) Sweet (syn. *Lablab lablab* (L.) A.Lyons)	Hyacinth bean, lablab, “okala” [Konso]	1–2000	South and North(?)		Pulse
Lathyrus sativus L.	Chicking vetch, grasspea, “guaya”	1800–2000		West Asia/ Eastern Mediterranean	Pulse

Table 1. Crops of the Ethiopian highlands: starch, bean and oil crops. (*Continuation*)

Crop	Common name	Elevational range (masl)	Native, origins zone	Introduced, origins centre	Main use category
Lens culinaris Medik. (= *Vicia lens* (L.) Coss. & Germ. in POWO)	Lentil, "miser", "sirota" [Konso]	1600–2700		West Asia	Pulse
Lupinus albus L.	White lupin, termins bean, "gibto"	1900–2700			Pulse
Phaseolus vulgaris L.	Haricot beans, "bolokie"	1–2100		Mediterranean	Pulse
Pisum abyssinicum A. Braun	Ethiopian pea, "ater"	1900–2600	North		Pulse
Pisum sativum L. (= *Lathyrus oleraceus* Lam. in POWO)	Garden pea	1700–2700		West Asia	Pulse
Vicia faba L.	Broad bean, "bekela"	1800–3200		West Asia	Pulse
Vigna radiata (L.) R.Wilczek	Mungbean	1–1800		India	Pulse
Vigna unguiculata (L.) Walp.	Cowpea, "adenguare", "ohota" [Konso]	1–2000		West Africa	Pulse
Brassica carinata A. Braun (= *Mutarda carinata* (A.Braun) D.A.German in POWO)	Ethiopian mustard, "gomenzer"	1500–2600	Southwest?		Oilseed
Brassica nigra (L.) W.D.J.Koch (= *Mutarda nigra* (L.) Bernh.in POWO)	Black mustard, "senafetch"	1500–2600		West Asia ?	Oilseed
Brassica rapa L. (syn. B. *campestris* L.)	Turnip rape, "gomenzer"	1500–2600		Mediterranean	Oilseed
Carthamus tinctorius L.	Safflower, "suf"	1700–2200		West Asia	Oilseed
Guizotia abyssinica (L.f.) Cass.	Niger seed, "noog"	1500–2400	North		Oilseed
Helianthus annuus L.	Sunflower, "ferenj suf", "jabar suf"	1–2500		North America	Oilseed
Gossypium arboreum L.; other *Gossypium* spp. later(?)	Tree cotton, "tit"	1000–2000		South Asia	Fibre, oilseed
Lepidium sativum L.	Cress, "feto"	750–2900	North	Mediterranean	Oilseed, vegetable
Linum usitatissimum L.	Linseed, "telba"	2000–3000		West Asia	Oilseed, (rarely as fibre)
Ricinus communis L.	Castor, "gulo"	1–2400	North ?	Lowland Africa ?	Oilseed
Sesamum indicum L.	Sesame, "selit"	1–1800		South Asia	Oilseed

Compiled from various sources, including Vavilov, 1935; Huffnagel, 1961; Westphal, 1974a; Westphal, 1974b; Jansen, 1981; Seegler, 1983; Le Houérou, 1984; Engels and Hawkes, 1991; Edwards, 1991.

Suggested subzone of domestication with Ethiopia are the authors' own hypothesis.

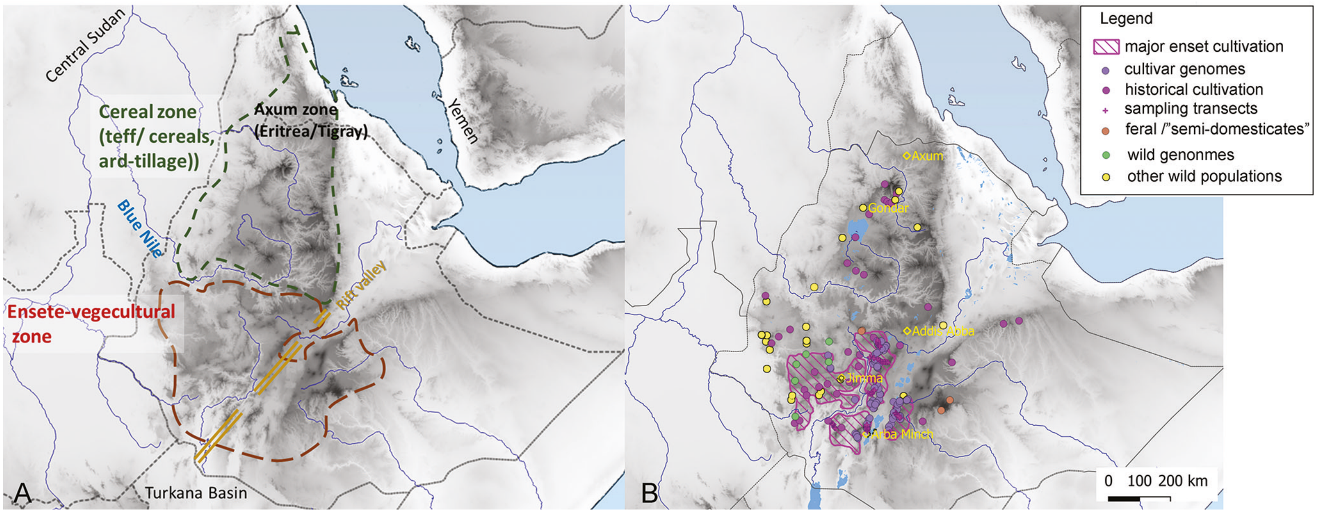


Figure 2. A: Map showing the Ethiopian landscape divided into two geographical zones, the cereal and vegeculture zones; B: Map showing areas of enset cultivation and wild populations, including those sampled in this study. Cultivar and wild genomes refer to populations included in the study of White *et al.* (2023); historical cultivation locations in the northern zone are derived from Stiehler (1948) and Simoons (1960); feral "semi-domesticates" are from Borrell *et al.* (2019); additional wild populations combine data from Simoons (1960), Borrell *et al.* (2019), and the north-eastern most population photographed in the inaturalist.org repository.

Part of the reason for such diversity in crop and agricultural systems lies with the diversity of environments created by the elevational gradients of the highlands, which stretch from typical African savanna environments (especially to the east) and tropical woodland environments (especially in the south-west) to cooler more temperate conditions at high elevations having an alpine environment. These higher elevations of the Ethiopian plateau provide environments well suited to familiar Mediterranean crops, such as wheat and barley, that reach their southernmost traditional limit at circa 6°N latitude in the southern highlands (by comparison, in south India, wheat and barley reach to only about 9°N). Wild olives (*Olea europea* ssp. *africana* (Mill.) P.S. Green, syn. *O. europea* ssp. *cuspidata*) abound in these mountains at elevations from 750 to 3000 m asl and grow throughout the Ethiopian plateau and further south in the eastern and southern African mountains (Green, 2002; Orwa *et al.*, 2009). Thus, in Ethiopia, African tropical lowlands, tropical montane and more temperate Mediterranean elements of wild flora and agriculture intermingle.

Another key factor in this diversity and agricultural productivity is the rainfall system. The highlands generally have high precipitation and two rainy seasons (Friis *et al.*, 2011, p.23; Viste *et al.*, 2013; Hildebrand *et al.*, 2019), although there is high interannual and local variability. Droughts are also frequent, especially in the northern highlands, and highland margins with lower average rainfall, and these seem to have increased since the 1970s (Viste *et al.*, 2013; Mera, 2018). During the summer monsoon or *kiremet*, the rains come off the Indian Ocean and provide increasing rainfall at higher elevations, with the highest and most reliable rains in the central and western highlands. There is also a short late winter/spring rainy season, the *belg,* which has higher rainfall toward the south and east providing a tailing of winter rains towards the northern plateau suitable for traditional winter Mediterranean crops.

The history of agriculture throughout Ethiopia has recently received attention through systematic archaeobotanical research (*e.g.* Beldados *et al.*, 2023; Ruiz-Giralt and Beldados, 2024; Meresa *et al.*, 2024), but data points are still few and far between especially in the southern highlands. More archaeobotanical research is needed to test and refine inferences that have been drawn largely from later historical and ethnographic patterns (*e.g.* Stiehler, 1948; Simoons, 1965; McCann, 1995; Hildebrand, 2003), and from historical linguistics (*e.g.* Blench, 2006; Ehret, 2011; Blažek, 2008). Most ethnoarchaeological research that draws on ethnobotanical observations of cultivation practices has focused on seed crops cultivated in the northern Ethiopian highlands, except for Hildebrand's in-depth study of enset and yams in the south-western region of Sheko (Hildebrand, 2003). There are also a wide range of papers on various aspects of enset ethnobotany (*e.g.* Gashe, 1987; Shigeta, 1991; Pijls *et al.*, 1995; Asfaw, 2018; Aneseyee *et al.*, 2022; Egziabher *et al.*, 2020; Olango *et al.*, 2014). A great challenge for ethnobotanical and ethnoarchaeological research in Ethiopia in general is the extreme agri-climatic and cultural diversity, and most notably in the south-west where enset is cultivated across dozens of different ethnicities.

The agricultural geography of Ethiopia is understandably a complex mosaic of seed cropping, vegeculture and pastoralism (Westphal, 1974a; Curtis, 2013). However, to simplify the patterns in dominant crops we divide the highlands into two geographical zones (Figure 2A): the northern zone with an emphasis on grain crops and the use of the cattle-drawn ard; and a southern zone that uses a greater range of hand tools and vegetatively propagated crops, including many tuber crops of which enset takes a special

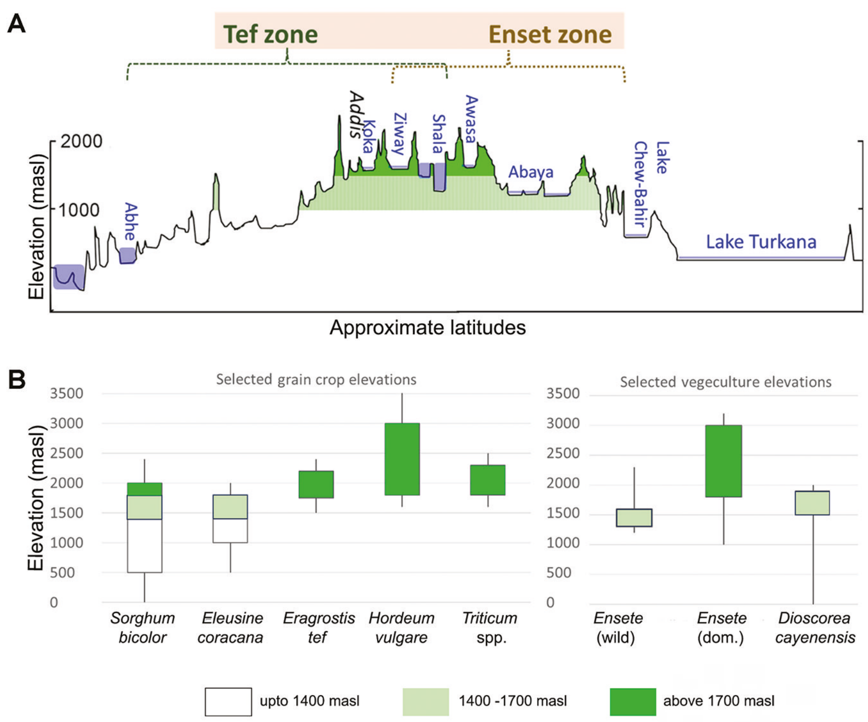


Figure 3. A: Diagram showing the elevational ranges in Ethiopia along a transect from north to south, and where t'ef and enset grow; lake basin names are indicated as is the approximate latititude of Addis Ababa (in italics). B: Box plots showing the elevation ranges for selected grain and vegetative crops cultivated in Ethiopia. Dark green indicates higher elevations where enset is a predominant crop (>1800 m asl), lighter shading indicates an intermediate zone of generally higher agrobiodiversity and less enset, and lower elevations (up to 1000 m asl) are not shaded.

and often predominant place. The upper Blue Nile acts as an approximate dividing line where it flows east to west through central western Ethiopia. Simoons (1960) separated these as "Southern Vegetative" and "Northern Seed" centres, also recognised by Murdock (1960). The northern zone is often associated with t'ef (*Eragrostis tef* (Zuccagni) Trotter), an indigenous domesticated Chloridoid millet. Additionally, practices of pastoralism are more important in the lower elevations around the plateau, and shifting cultivation is more important in the less densely populated lower slopes of the highlands. In the north, besides *E. tef,* cultivation of wheats (*Triticum* spp.), sorghum (*Sorghum bicolor* (L.) Moench), finger millet (Chloridoid *Eleusine coracana* (L.) Gaertn.), barley (*Hordeum vulgare* L.), oat (*Avena abyssinica* Hochst.), lentil (*Vicia lens* (L.) Coss. and Germ., syn. *Lens culinaris* Medik.), and broad bean (*Vicia faba* L.) abound (Table 1). These northern agricultural conditions have often been characterised as a northern ox-plough agricultural complex (Simoons, 1960; McCann, 1995). Archaeobotanical evidence from the northern highlands that indicates the presence of barley, emmer wheat, lentil and flax that were present from circa 3000 BP (Beldados *et al.*, 2023; Meresa *et al.*, 2024), while the earliest possible t'ef is currently around 2400 BP (Meresa *et al.*, 2024; Ruiz-Giralt and Beldados, 2024).

As one moves into the southern zone, all these cereals are also traditionally grown but their importance decreases as fields are interspersed with cultivated groves of enset and an increasing range of tuber crops. While potatoes are a recent crop of growing importance, more traditional and ancient tubers include the oromo dinich (*Coleus maculosus* ssp. *edulis* (Vatke)), yams (*Dioscorea cayenensis* Lam. and *D. abyssinica* Hoch.), anchote (*Coccinia abyssinica* (Lam.) Cogn.) and several regional aroids (*Arisaema schimperianum* Schott, *Amorphophallus abyssinicus* (A. Rich.) N.E.Br., *Sauromatum venosum* (Alton) Kunth), as well as introduced Asian *Colocasia esculenta* (L.) Schott, and Asian greater yam (*Dioscorea alata* L.). It is worth noting that wild enset occurs in both zones, although cultivation is more prevalent in the south (Figure 2B). Archaeobotanical evidence from the southern zone is limited and late (Ruiz-Giralt and Beldados, 2024).

Because of the elevational gradients not all crops can be grown everywhere but they can be characterised to some extent in relation to the elevation ranges over which they occur. Based on reported ranges of crops (taken from Westphal, 1974a), we regard those that do well about 1800 m asl as representing an upland set of crops, whereas those that mainly occur below 1000 m asl as predominantly lowland (Figure 3) This defines an overlap zone (or intermediate range) where agrobiodiversity is especially high from 1000 to 1800 m asl. Within this zone, enset is a minor crop, which increases in importance above 1700 m asl. Of note is that wild enset is reported mainly from 1200 to 1600 m asl (although it can be found up to 2300 m asl according to Westphal (1974a), and up to 2700 m asl based on collections made in relation to our current project). What this suggests is that enset cultivation and domestication could have involved a process of upward translocation over time, facilitating increasing populations at higher elevations. This also impacted the crop, as enset plants at higher elevation tend to mature more slowly, grow larger, and flower at later ages.

While the core region of enset domestication is in southern Ethiopia, its cultivation in the past may have been more widespread in the north (Brandt *et al.*, 1997). This might be inferred from the scattered occurrences of traditional or historical cultivation, as well as wild populations occurring in the north (Figure 2B). The retreat of enset from the northern region could have resulted from the spread of other crops and agricultural practices that displaced enset. Over time there have been several waves of cultural, and presumably population, diffusion from the north. Some posit an initial spread of pastoralism with use of wild grains, perhaps 4000 BP (Curtis, 2013), with later cereal farming agro-pastoralists (from 3000 BP), followed by a later diffusion of more dedicated farmers with ard-ploughs and a more diverse range of cereals. The archaeological Musaceae leaves from excavations at Kumali in the Keffa cultural zone of Ethiopia are more recent than 1700 years ago (Hildebrand *et al.*, 2010) and thus provide no insight into inferred early cultivation. Despite speculation that enset domestication could have happened from 10,000 to 5000 BP (Brandt *et al.*, 1997), we currently lack empirical evidence.

Historical linguistics and the distribution of language groups can provide some hypotheses for the history of agriculture and crop processes in southern Ethiopia. While some scholars have made strides in this direction already (*e.g.* Ehret, 2011), they offer little insight on the far south-west or on enset. Much of that region includes areas where the obscure Omotic language family is represented. Blench (2007; 2008) has made some initial progress in collecting Omotic vocabulary relating to livestock and some of a highly diversified terminology for enset (Blench, 2007), although an ethnographically informed collection of terms relating to tools and the stages of processing enset and its various food products is needed and is being inventoried during the current project. Despite past assertion that Omotic is a sub-branch of the larger Afro-Asiatic family (*e.g.* Bender, 1971; Blench, 2006; Ehret, 2011; Blažek, 2008), some recent assessments dispute this because shared traits amount to a small amount of vocabulary that could be early loan words (Hayward, 2008; Thiel, 2012). The Omotic group itself is traditionally divided into a core Northern Omotic (*e.g.* Wolaita, Gamo, Basketo, Sheko) and a southern group (*e.g.* Dizi, Hamar, Karo), and it is even unclear if these evolved from a common ancestor or have a long and early history of interaction with word borrowing (Thiel, 2012). Taking this to be the case we can hypothesise that Omotic and surrounding languages were also present in south-west Ethiopia, which would have been a highland region of considerable ethnolinguistic diversity. Enset was likely brought into cultivation before the arrival of other food-producing immigrants. As Blench (2007) did not identify a coherent shared vocabulary it is likely that hunter-gatherers speaking a range of Omotic languages existed before enset cultivation spread among them. The first immigrant groups would have been Cushitic speakers, who might have brought livestock and some cereal cultivation (Ehret, 2011), although Blench (2008) has suggested that cattle and sheep/goat may have been introduced at different times and via different sources into south-west Ethiopia. Zooarchaeological evidence indicates the appearance of livestock from around 2400 BP (Lesur *et al.*, 2014; Arthur *et al.*, 2019), likely associated with cattle-centric rock art (Negash, 2020). Cereals, or at least barley, are evident by this time (and possibly earlier) based on a single undated grain of barley in the early ceramic levels at Mota Cave in the Gamo region, Ethiopia (Arthur *et al.*, 2019). We noted that there is still no evidence for sorghum or finger millet as predicted by Ehret (2011). Other Cushitic speakers settled in the south-eastern parts of the highlands and took up enset cultivation, *i.e.* the Highland East Cushitic subfamily (*e.g.* Burji, Sidamo, Hadiyya). Later, the diffusion of greater cereal diversity (perhaps including t'ef) can be expected to have taken place as Ethio-Semitic speaking plough (ard) cultures spread in the highlands from the north through central and south Ethiopia. While the spread of the plough can be mapped (*e.g.* Stiehler, 1948), there remains no clear evidence for when this happened. The Gamo region site of Tuwatey Cave in southern Ethiopia shows a diversity of cereals (emmer, barley, sorghum, finger millet, as well as cotton) by 500 BP, which suggests that this later diffusion may have taken place before 500 BP. Sorghum and finger millet, however, could have arrived separately as they can more readily be cultivated without the scratch plough, as observed in the recent Konso area, Ethiopia (Förch, 2003). T'ef, by contrast appears closely linked to the ard and may have arrived after the other cereals; throughout the south-west this cereal is normally known by variants of its Amharic name suggesting a recent arrival; its Amharic name derives from a more ancient Cushitic term that was a more generic grain food (Ehret, 2011).

3. Enset uses, food processing and food types

Unlike the banana which produces one of the world's most important fruits, the useful parts of enset are the pseudostem, the corm and the leaves, although sometimes the stalk of the inflorescence is included in the fermentation process of *kocho* (Tsegaye and Struik, 2002). Enset leaves, normally the young ones, are used in similar ways as the banana (Castillo and Fuller, 2024; Kennedy, 2009); such as for wrappers, fodder, and for fibre turned to cordage (Figure 4). However, the three main foods *kocho, bulla* and *amicho* are derived from the enset pseudostem and corm.

To process *kocho* and *bulla*, enset plants are usually felled before flowering or close to maturity (circa 3 to 7 years of age depending on the geographic location since altitude affects flowering times). From our interviews, enset is harvested at different ages depending on altitudinal ranges at which the crop exists. Crops may be harvested as young as circa 3–4 years old in lower altitudes or circa 6–7 years old in higher altitudes. On the other hand, young enset plants are harvested for the corm (*amicho/uta*). The corm is boiled and eaten like other starchy vegetative crops, such as taro and the potato. It is a good emergency resource because the corm remains stored underground until it is needed, only then would a family need to cut down the enset and harvest

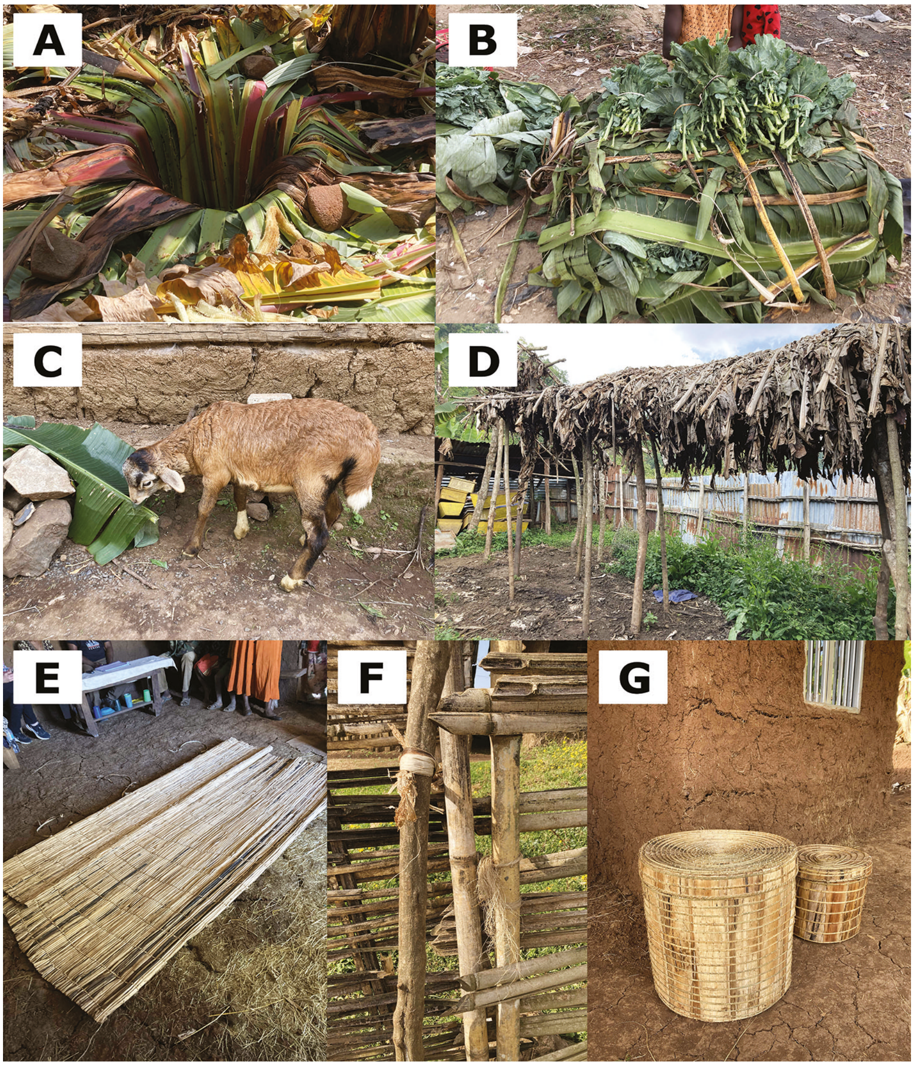


Figure 4. Different uses of enset leaves. A: Lining of a fermentation pit; B: Wrapping vegetables and agricultural produce; C: Fodder; D: Roofing material; E: Matting; F: Cordage for fencing; G: Baskets.

the corm which can feed an entire household.

The work of processing enset is the exclusive domain of women, who work as a group and normally are from the same household or neighbourhood, whereas some of the more manual aspects of the cultivation such as transplanting enset is typically undertaken by men. In the garden where the enset plantation is located, a processing area sometimes lined with enset leaves is set up to make *kocho* and *bulla*

Figure 5. A: Scraping the pseudostem; B: Fibres line a mesh to be used to squeeze out the starchy liquid; C: Squeezing the starchy liquid from the pseudostem and corm mixture; D: Pounding and pulverising the corm.

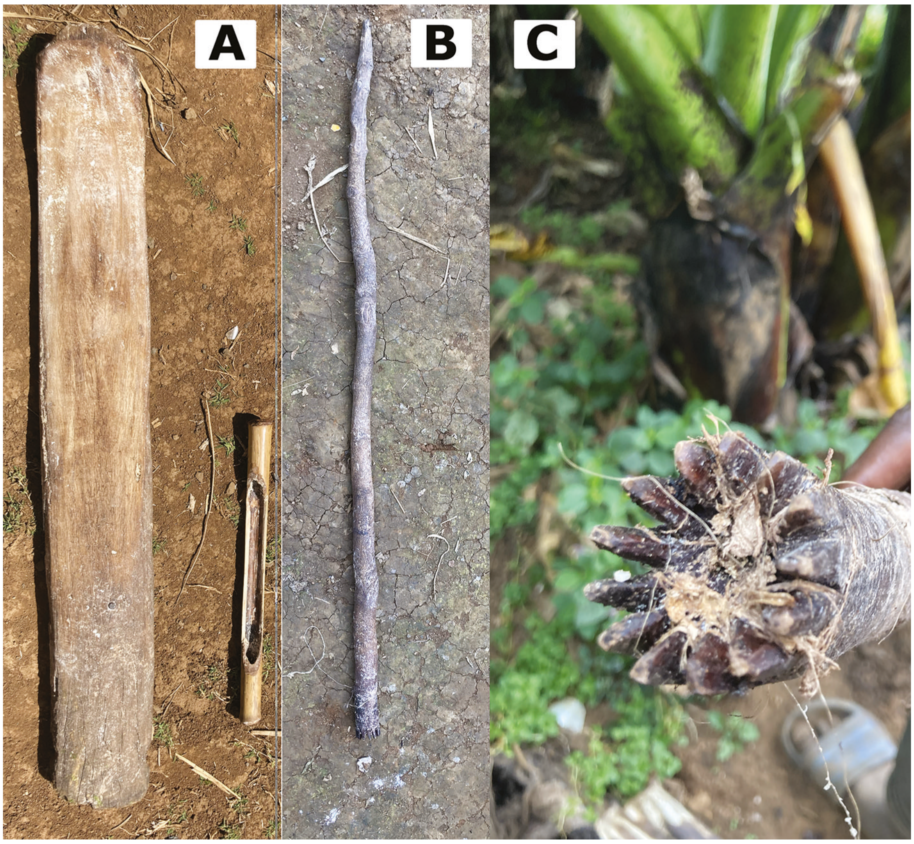


Figure 6. Tools used in enset processing. A: Wooden plank and bamboo scraper; B: Wooden pounder used for pulverising the corm; C: Detail of serrated end of wooden pounder.

(Figure 5). The pseudostem is placed on a wooden plank and scraped with a bamboo scraper (Figures 5A and 6A). The corm is pulverised with a wooden tool that has a serrated end and is mixed with the pseudostem preparation that will be used to make *kocho* (Figures 5D, 6B and 6C). Scraping the starch from the pseudostem leaves behind the fibrous parts which can be later turned into cordage and today is often sold in bulk (see below discussion). The scraped pseudostem and pulverized corm mixture is placed onto a mesh covered with an enset fibre layer and twisted to remove the starchy liquid resulting in a mushy product which is then fermented in a large underground pit lined with enset leaves (Figures 5B, 5C and 4A). Enset is initially fermented for a few weeks after which it is edible but can then be stored in pits for up to several years, undergoing ongoing fermentation, until a family decides to cook or sell the dough. The fermented dough is prepared as a bread-like food type that can have variable thickness, and sometimes as a crumblier foodstuff. The starchy liquid or by-product when processing *kocho* is dehydrated and is known as *bulla* which is the premium enset product. *Bulla* is a powder which is then cooked into a porridge or made into pancakes.

4. Phytolith analysis

4.1 Uses and aims

The study of phytoliths is recommended as an alternative, or in conjunction, to the study of macroremains in situations where plant remains, such as seeds, fruits and parenchymatous tissues, do not preserve. Phytoliths have proved useful for tracking bananas archaeologically since domesticated bananas are parthenocarpic and do not produce seeds (Lentfer, 2009; Mbida *et al.*, 2001). Furthermore, banana phytoliths are considered diagnostic and distinguishable from other taxa (Ball *et al.*, 2006; Vrydaghs *et al.*, 2009). The phytoliths produced in the leaves are described as VOLCANIFORMS, troughs, truncated cones or cavate (Ball *et al.*, 2006; Piperno, 2006; Horrocks and Rechtman, 2009; ICPN 2.0, 2019). These observations remain valid for enset, whose phytoliths like those of bananas should be identifiable not just to genus but to finer taxonomic levels. Also, the processing of enset into the different food types does not yield any seeds. Archaeobotanical evidence across multiple sites and various ages are needed to track enset's spatial and climatic expansion, but this requires robust methods for the identification of enset phytoliths to distinguish cultivars and contrast these with similar introduced crops like the banana. Therefore, the identification criteria need to be refined to find enset in archaeological sediments. Our project aim is to provide a baseline for the identification of enset phytoliths from the leaves, seeds, pseudostem and food products of modern domesticated and wild specimens, and to do this required a large comparative study of *Ensete, Musa* and *Musella*.

Tomlinson (1959) identified two types of phytoliths in *Musa*; trough-like (*i.e.* VOLCANIFORM) and spherical (*i.e.* SPHEROID) silica bodies. He includes two species of enset in his anatomical description of Musaceae, *Ensete gilletii* (De Wild.) Cheesman (synonym of *Ensete livingstonianum*

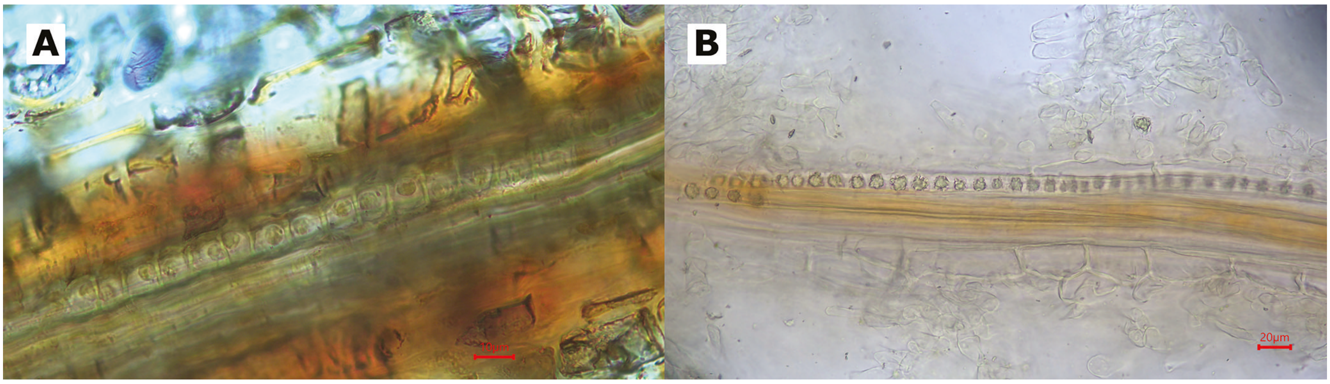


Figure 7. A: Chain of Musaceae Volcaniform phytoliths from the leaf of domesticated enset, Temperate House, Kew Gardens. B: Chain of Spheroid phytoliths with a nodular surface from the leaf of enset (ID 3189), collected in Ethiopia.

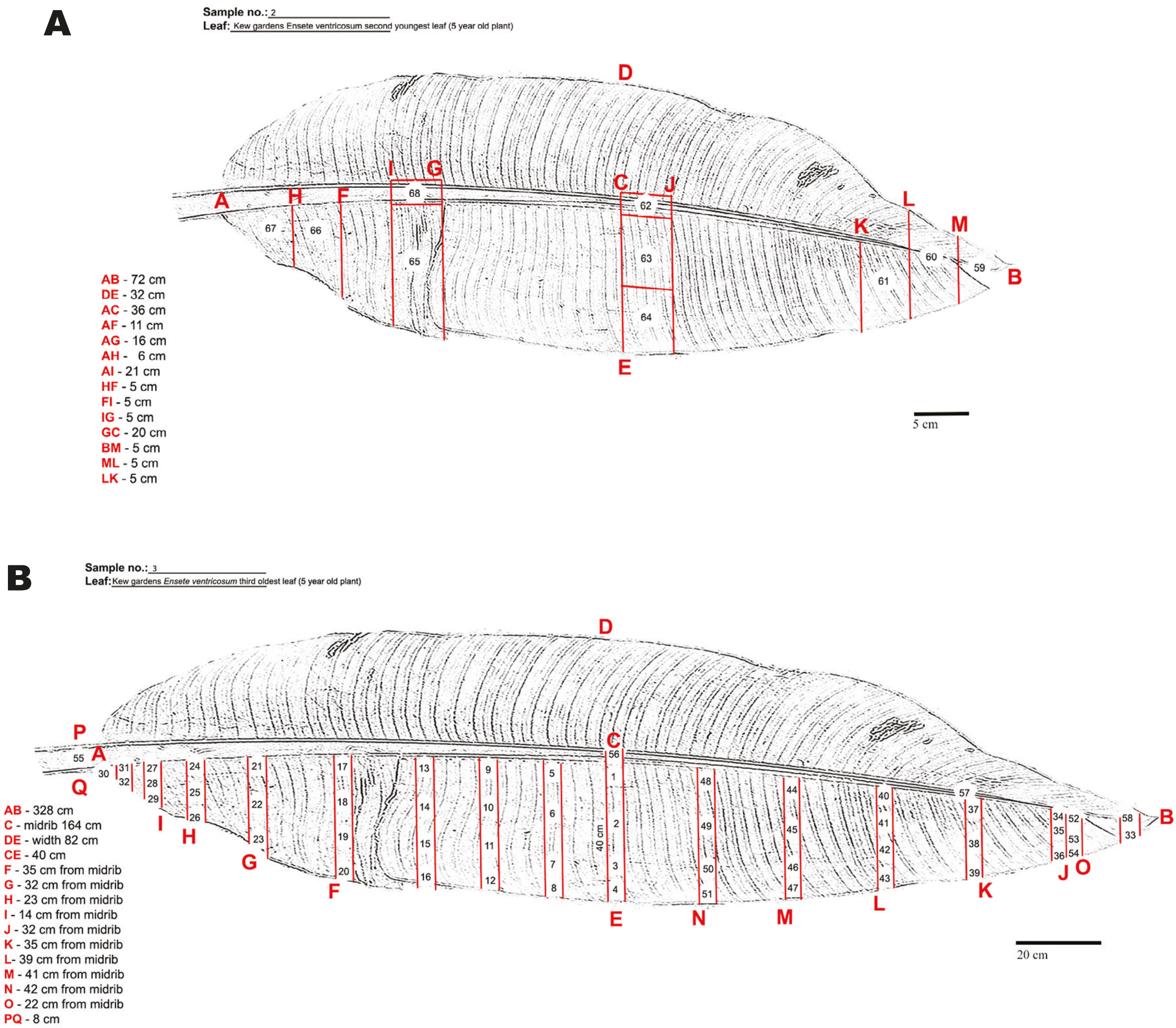


Figure 8. Top: Visual map of samples taken from the youngest leaf. Bottom: Visual map of samples taken from the oldest leaf. Both leaves are from the domesticated enset, Temperate House, Kew Gardens.

(J.Kirk) Cheesman) and *Ensete arnoldianum* (De Wild.) Cheesman (synonym of *Ensete ventricosum*) and found no "trough shaped" silica bodies in the former, and an intermediate of the two *Musa* types in the latter. In *Musa*, he located the phytolith chains on the fibres alongside the vascular bundles. Thin sections done on *Ensete ventricosum* collected in the Temperate House, Kew Gardens and specimens collected in Ethiopia show their location (Figure 7) corresponding to Tomlinson's description. The phytoliths are located at a depth of at least more than three cell layers (Tomlinson, 1959) which makes their examination difficult since the epidermal cells tend to obscure the lower layers. Therefore, in the preparation of thin sections, the specimens were placed in a solution of 5% Sodium Hydroxide for 48 hours and then scraped with a sharp blade to expose the vascular bundles and fibres.

Phytolith research on enset has normally been undertaken to compare and differentiate these from banana phytoliths (Ball *et al.*, 2006; Vrydaghs *et al.*, 2009). Here, we focus on the identification and the variations of phytoliths within enset. The project dataset includes wild and domesticated enset leaves sampled in Ethiopia and sequenced at Royal Botanic Gardens, Kew, processed enset and food products made from enset collected in Ethiopia, as well as one domesticated enset plant and other species belonging to the Musaceae family growing in the Temperate and Palm Houses at the Royal Botanic Gardens, Kew. In this paper, we focus on observations derived from the phytoliths of the domesticated 5-year-old flowering *Ensete ventricosum* plant which was growing in the Temperate House, which are confirmed by examination of a range of enset specimens collected from farms in Ethiopia.

4.2 Methodology

We sub-sampled as many plant parts as possible from this one individual, including the leaves, pseudostem, corm, infructescence, bracts and roots. From the youngest leaf, ten leaf cuttings were taken of which seven were processed for phytoliths. There were 57 leaf cuttings taken from the oldest leaf and eleven were processed (Table S1 provides details of the samples). Visual maps of sampled areas of the leaves were drawn (Figures 8A and 8B). One sample each from the pseudostem, corm and root were also processed and examined for phytoliths.

The dry-ash method was used to extract phytoliths from the modern reference material (Piperno, 2006). We cut ~2×2 cm sections of plant material and washed it with distilled water. These were placed in small crucibles with lids into a drying cupboard at 50ºC for one hour or until the samples were dry. The crucibles were placed in the muffle furnace heated to 500ºC for 2 hours. After the samples had cooled, the contents, which were ashed, were transferred to small tubes and a small amount of 10% HCl was added to remove the carbonates until the samples stopped fizzing. Deionised water was then added to the tubes and centrifuged four times (once at 2000 rpm for 5 minutes and three times at 2000 rpm for 2 minutes). Finally, some of the solution was mounted onto a slide with Entellan solution and onto Scanning Electron Microscopy stubs. A Nikon Eclipse LV100 high-powered microscope fitted with a x100 oil immersion lens and GX Capture software was used for imaging. For finer resolution imagery, a Hitachi S3400 SEM was used.

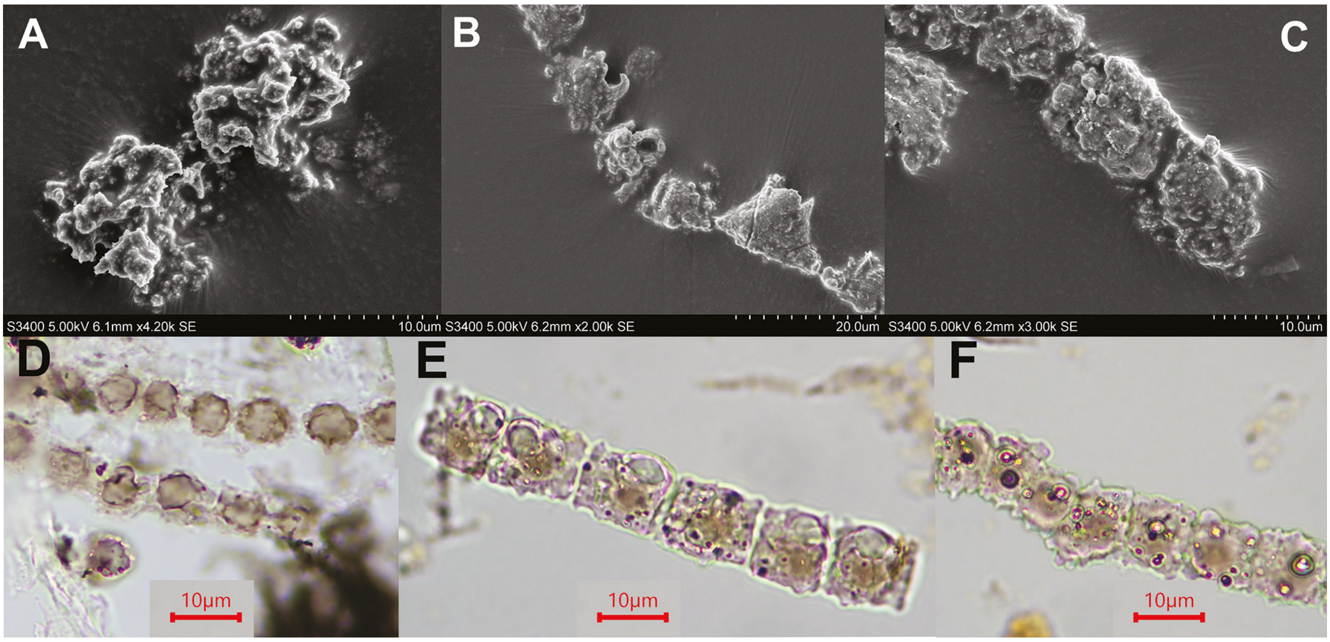
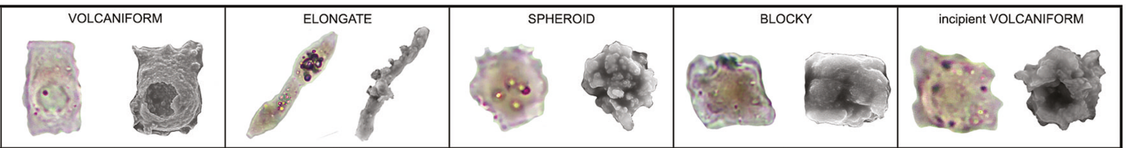


Figure 9. Images of phytoliths from leaf cuttings taken from enset located in Ethiopia. SEM micrographs of A) Spheroid phytoliths from the young leaf 6231; B) Musaceae Volcaniform phytoliths from the old leaf 6231; C) Spheroid phytoliths from the old leaf 6231; High-powered microscopy images of D) Spheroid phytoliths from the young leaf 6285; E) Musaceae Volcaniform phytoliths from the old leaf 6285; F) Spheroid phytoliths from the old leaf 6285.

Table 2. Phytolith types found in domesticated enset identified using high-powered and scanning electron microscopy.



Age of leaf	location in leaf	VOLCANIFORM high-powered	VOLCANIFORM SEM	ELONGATE high-powered	ELONGATE SEM	SPHEROID high-powered	SPHEROID SEM	BLOCKY high-powered	BLOCKY SEM	incipient VOLCANIFORM high-powered	incipient VOLCANIFORM SEM
young	apex			■	■	■	■				
	middle	■	■	■	■	■	■			■	■
	base					■	■				
	midrib			■	■	■	■	■	■	■	■
old	apex	■	■			■	■				
	middle	■	■	■	■	■	■			■	■
	base	■	■			■	■			■	■
	midrib	■	■			■	■	■	■	■	■
pseudostem		■	■			■	■	■	■	■	■

4.3 Results

The examination of phytoliths extracted from the domesticated enset grown in the Temperate House, Kew Gardens, illustrates that there are several morphotypes in one plant, including the typical Volcaniform type associated with Musaceae. Phytoliths were found in the leaves, midribs and pseudostem of enset. On the other hand, no phytoliths were found in the roots or corm of this individual (*cf.* Tomlinson, 1959).

Depending on the age of the leaf and their location in the leaf, different phytolith morphotypes were identified. In general, the morphotypes can be grouped into Musaceae Volcaniform, Spheroid, Elongate, Blocky phytoliths and a subgroup which we have tentatively named "incipient Volcaniform" which do not conform to the typical Musaceae Volcaniforms but display slight depressions where the crater of a Musaceae Volcaniform would be located (Table 2).

The microscopy work revealed that Spheroid phytoliths were present in all the samples studied, which include the apices, bases, middle area and the midribs of both the youngest and oldest leaves sampled, as well as the pseudostem. Blocky phytolith types were present in the midribs and pseudostem. Elongate phytoliths were identified in more areas of the youngest leaf than in the oldest leaves. The Musaceae Volcaniform phytoliths were identified across all locations in the oldest leaf but only seen in the middle portion of the youngest leaf. Musaceae Volcaniform phytoliths were also present in the pseudostem. Finally, the "incipient Volcaniforms" were found in some parts of the leaf, but always in the midribs and pesudostem.

Samples from two individual enset plants from Ethiopia show Spheroid phytoliths present in both the young and old leaves but Musaceae Volcaniforms were only present in the old leaves examined. These morphotypes correspond to some of those examined in the individual plant from the Temperate House, Kew Gardens (Figure 9).

4.4 Discussion: filling in the gaps of phytolith research

We present here some observations based on the individual enset plant from the Temperate House in Kew Gardens with the intention of documenting the phytolith morphotypes. The phytolith analysis is on-going but the main result from our work is the documentation of a variety of phytoliths found in enset plants, not just the Musaceae Volcaniforms. We also provide comparative results from the examination of phytoliths coming from young and old leaves taken during our fieldwork in Ethiopia where we collected an old and a young leaf specimen from the same individual plant.

Following the ICPN 2.0 (2019), Chen and Smith (2013), Vrydaghs *et al.* (2009) and our own observations, we define the morphotypes in our study as follows; Spheroid phytoliths have a sphere shape but with variations ranging from perfectly spherical to slightly ellipsoidal and may contain surface ornamentation. Chen and Smith (2013) define these as globular. Elongate phytoliths are long and irregular with variations ranging from dentate to sinuate. Blocky phytoliths are more cubic-like than they are sphere-shaped. Chen and Smith (2013) define these as tabular. The Musaceae Volcaniform phytoliths are characterised by a base and cone with a depression in the centre of the cone forming a crater. From the polar view, they resemble Chen and Smith's (2013) troughs. The "incipient Volcaniforms" are morphotypes between a Spheroid and a Musaceae Volcaniform wherein a slight depression is discerned from the polar view.

Phytolith work on Musaceae has focused on the Volcaniform types, but our work demonstrates that there are at least five different morphotypes found in enset, and many of these are more common and more widespread across the plant. Archaeobotanists in the past have been focusing on identifying banana domestication and bananas versus enset through the identification of mainly, if not only, the Musaceae Volcaniforms (*e.g.* Ball *et al.*, 2016; Neumann and Hildebrand, 2009; Power *et al.*, 2019), but our work shows that this morphotype is just one of at least four morphotypes which does not necessarily occur in all the parts of the leaves. This is one of the reasons why enset has not been identified in archaeological deposits. To identify enset in archaeological sediment, researchers should look beyond the Musaceae Volcaniforms.

Our observations show that a different range of morphotypes can be expected depending on the age of the leaves. In the case of the oldest leaf, every location sampled (apex, middle, base and midrib) yielded Musaceae Volcaniforms. We therefore propose that the presence of

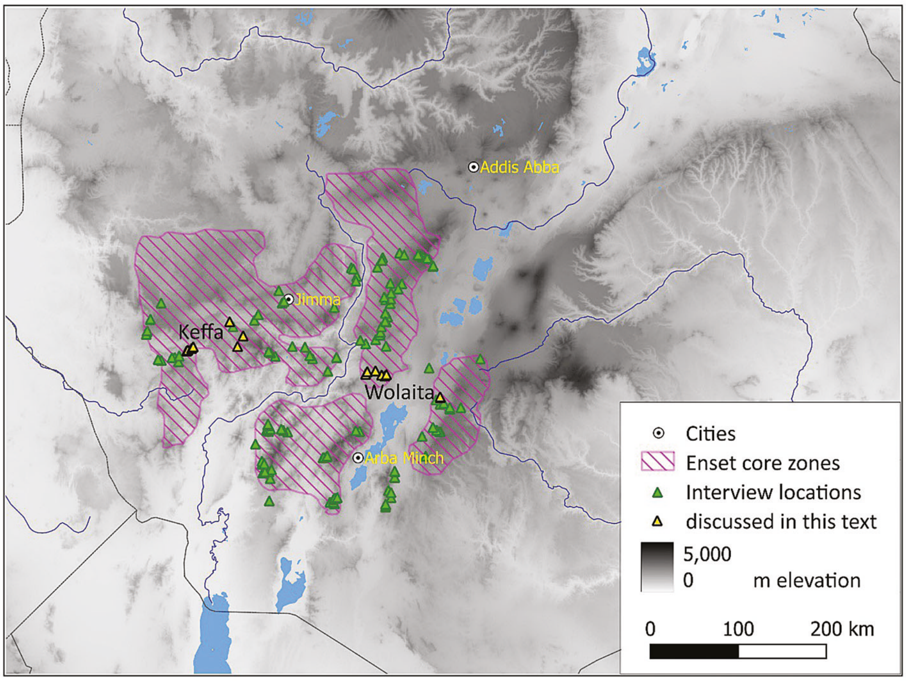


Figure 10. Map showing the locations of ethnobotanical interviews in relation to the core enset zone (from Figure 2), with those areas discussed here highlighted.

Musaceae Volcaniforms probably signifies that enset is present in the sediment samples, but these would most likely come from the old leaves of enset. This would then be linked to usage of enset, including the leaves and in what situations people are likely to use old leaves. However, it is probable that young enset leaves are preferred to old leaves for the purposes of fodder, craft and other daily uses, such as wrapping. In that case, archaeological sediments would not necessarily contain Musaceae Volcaniforms. For example, the Gurage people from central Ethiopia make a distinction between leaves (*q't'er*) and the outside layers and dried leaf sheaths (*enewa* and *wedere*) of enset and their specific uses (Hailemariam, 1991). *Q't'er* probably refers to the younger leaves and are used for baking bread, tablecloths, fodder and the different processing stages of enset (Hailermariam, 1991).

Our work using two microscopy techniques shows that the use of high-powered and electron microscopy can detect the various morphotypes found in enset. However, as expected, the finer resolution of the SEM provides details which would otherwise be missed, such as the ornamentation on the surface of the phytoliths which we observed.

5. Ethnobotanical research

5.1 Methodology

The south-west is extremely diverse, ethnically and environmentally, and our project is working across 20 different cultural regions. To facilitate the large numbers of locations we developed group interviews that incorporate on average four households and between 7 to 10 locations within each of the regions depending on size (Figure 10). Ethnobotanical interviews were undertaken with our partners at Addis Ababa university over six trips in 2022 (November), 2023 (January, May, November) and 2024 (April, July–August). Our process followed guidelines provided by the Code of Ethics of the International Society of Ethnobiology (International Society of Ethnobiology, 2006). The aims, potential outputs and methodology of the study were explained to participants prior to interviews.

Group interviews included asking about which varieties are grown in farmers' villages using a "free listing" approach (Martin, 1995). They were then asked which of these each of them grew, the varietal uses, and whether the varieties were perceived as increasing or decreasing in use over the last 20–40 years. Another key component of the interview was asking about the relative role of enset (at species level) for different uses over the last few decades to track changes in the role of enset for food, fodder, and materials on a household level versus commercial uses, and the frequency of eating different enset food products today and in the past. Additionally, each farmer was asked about the amount of land they use for enset cultivation at present and in the past. Cultivation and processing practices were also documented in each region to evaluate similarities or differences across cultural groups and altitudes. These methods draw on approaches developed in similar research in Sudan and Guinea on diversity change in living memory (Ryan *et al.*, 2022; Burton *et al.*, 2024).

Here, we present some initial illustrative results from the group interviews in two cultural zones, Wolaita and Keffa. We select these regions to present preliminary findings here as they are regions with archaeological sites which hold the potential for examining long-term enset histories. As the project progresses, these results will be compared more fully across the 20 cultural regions and the dataset as a whole evaluated.

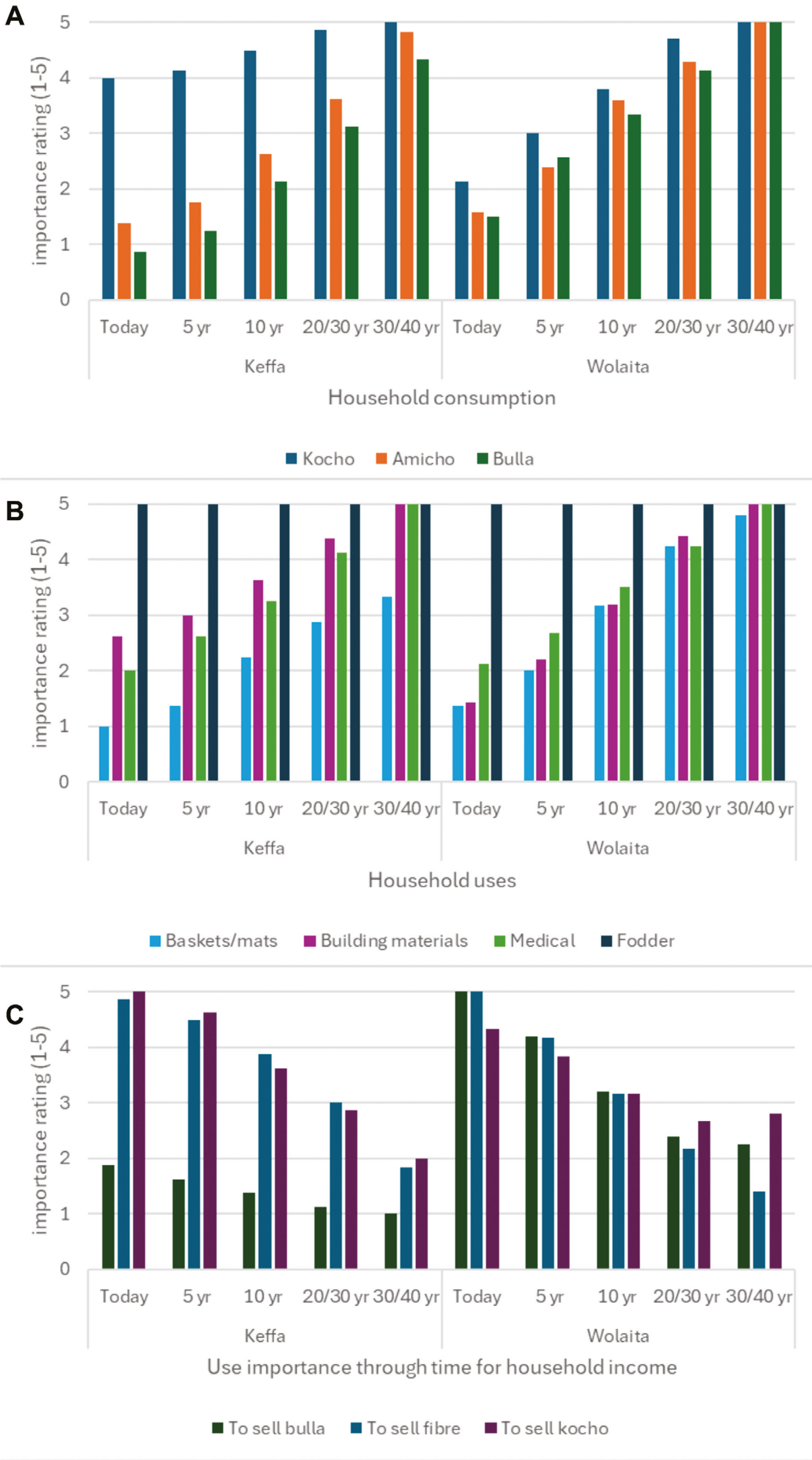


Figure 11. Temporal trends in the average importance rating for enset from (0 – low to 5 – high), for A) household consumption, B) other household uses, and C) household income.

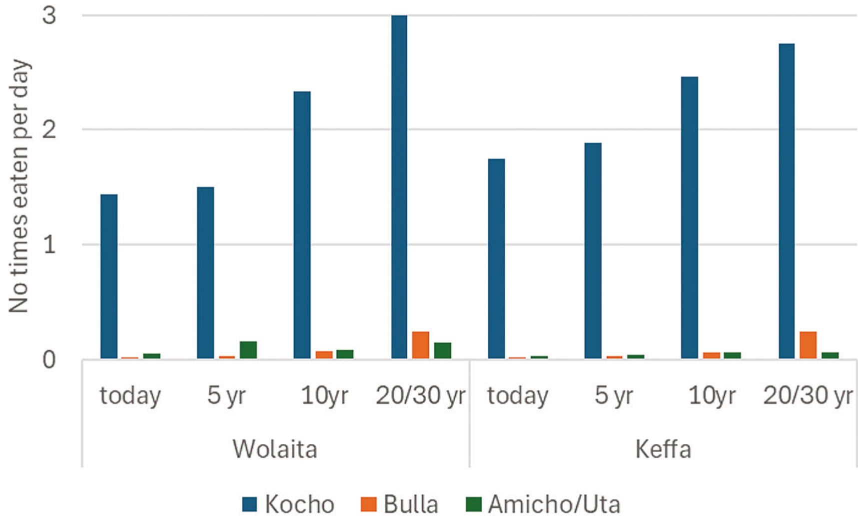


Figure 12. Temporal trends in the average frequency of consumption per month.

5.2 Results

Landraces in Wolaita and Keffa (and more broadly) were all multipurpose as well as often being selected for particular traits. In nearly all interviews certain landraces were reported as being "best" for particular uses, such as for different food products, construction or possessing traits such as resilience to drought or disease. Landrace use for medicinal purposes (human, and animal) was more variable than other uses. In Keffa, 70% (n=78) of landraces were identified/cited for medicinal purposes, whereas in Wolaita only 33% of 77 landraces were cited. Medicinal uses were noted mostly as for healing bones and for mothers after giving birth. Use data was simplified in interviews for analysis (*e.g.* basketry, construction, ceremonial) due to the interview length and questionnaire format to enable comparisons between both landraces and regions. However, at the end of the interview we also asked to see objects made from enset, to better understand its use in crafts and construction.

Critically, most landrace varieties were reported as declining. Farmers reported 75% (n=57) landraces in their farms as declining in Wolaita, and 82% (n=68) in Keffa. When individually named landraces were considered by averaging results from repeated occurrences, 95% (n=24) in Wolaita and 82% (n=33) in Keffa were perceived as being grown less today than in the past. The higher percentage of decline in Wolaita when averaged by name reflects 5 landraces that commonly occurred across the interviews declining in some locations but being stable in others. In Keffa, disease was cited for the decline of specific landraces, whilst in Wolaita disease and drought were mentioned.

In both the Wolaita and Keffa zones, there is a decline in the perceived importance of enset cultivation for household consumption and uses, except as fodder, and instead there is an increase in its use to sell for income (Figures 11A, 11B and 11C). Farmers explained that the historic use of enset for household construction, crafts and medicines is being replaced by modern materials and treatments. For example, enset fibre has developed a new role in being used for manufacturing commercial roofing, and farmers sell it directly to traders. Similarly, *bulla* and *kocho* are being sold to local markets for income.

A similar trend is seen in a reduced frequency of enset consumption (Figure 12). *Kocho* is most frequently consumed today and in the past. Consuming the corm as *amicho/uta* (like a root vegetable) was cited as more important in the past, with its role being seasonal or for food security, whilst *bulla* was described as for special occasions. Farmers also cited more cereals being eaten today than in the past. The data for consumption includes enset bought from markets and restaurants, so provides a slightly different insight than the information on the "perceived role of enset cultivation for household consumption".

Farmers were also asked about the relative importance of enset to other food crops. Enset was cited as the most important today in only 2 out of 8 group interviews in Wolaita, but as the most important crop by all groups in the past. Similarly, in Keffa, all 8 groups cited enset as the most important crop in the past, but in contrast, 6 of the groups still cited it as the priority today. Crops that have now become a greater priority included taro, cassava and maize in Wolaita and maize in Keffa.

5.3 Discussion

The temporally focused ethnobotanical interviews in our study help to reveal major shifts within enset cultivation and use practices in recent decades that is suggestive of at-risk varietal diversity and cultural heritage. Reasons cited for these changes by farmers include market forces, crop disease, drought and shifts towards new diets, but trends vary across different regions. It is worth noting that the major town of Sodo in Wolaita is considerably larger than Bonga, the regional capital of Keffa, which may influence the extent of market forces on household uses and be an additional reason for the slightly steeper decline observed across some of the analyses in Wolaita.

The interview data provides a current and recent past baseline from which one can connect the deep time histories of the crop and genomics data. This is important because the "recent" past data helps calibrate whether the current diversity in different regions reflects actual continuity (*e.g.* low diversity today and low diversity in living memory) or modern change (*e.g.* low diversity today and high diversity in living memory). The centrality of enset as the most important crop in the food system relative to other species is also documented in the anthropological accounts from the mid-twentieth century in Wolaita providing a comparative datapoint to the farmers recollections about the past (Haberland *et al.*, 2023).

The complex range of enset landraces and uses in Keffa and Wolaita is also described in other ethnobotanical studies (Asfaw *et al.*, 2024; Olango *et al.*, 2014; Tsehaye and Kebebew, 2006; Worojie and Geremew, 2025). There are also accounts of enset-based crafts and construction in Wolaita from anthropological studies from the mid-twentieth century, some of which have become less common today (Haberland *et al.*, 2023). The relationships between enset landrace diversity and cultural uses indicates the importance of Local Ecological and Technical Knowledge (LETK) in the creation and maintenance of agrobiodiversity.

6. Conclusions

For the phytolith work, our preliminary data and observations suggest there is a large amount of variation in morphotypes coming from enset plant parts, including the leaves, and although Musaceae Volcaniforms may be present, their presence is a factor of the plant part observed, and in the case of leaves, the age and location of the leaf. We therefore hope to address the dearth of enset phytolith identifications in archaeological sediments by proposing that the other phytolith morphotypes need to be considered. Also, when discussing the use of enset in the past, the morphotypes will help elucidate whether people were probably using young leaves as opposed to old leaves depending on the range of enset phytoliths found in the archaeological sediments. We also corroborated our work using samples collected from fieldwork in Ethiopia.

Moving forward, we will establish a protocol for enset, which can be extended to other crops (*i.e.* bananas), by providing fine resolution drawings and morphometric data. This will include the results from our wider study of enset processed plant parts, food products, and the old and young leaves from the same enset plant collected during fieldwork in Ethiopia. We will also include wild enset and the other species of Musaceae sampled from the Temperate House, Kew Gardens.

From our ethnobotanical work, we can confirm that in recent decades there is indeed a decline in the use of enset at the household level as well as many landraces becoming perceived as rarer in Keffa and Wolaita. Further ethnographic analysis across twenty cultural zones will help better understand these temporal trends and how they contribute to genetic diversity patterns and highlight areas most at risk of varietal decline. More widely, this research highlights the importance of indigenous crops for resilience to climate change, of Local Ecological and Technical Knowledge and Cultural Heritage in conserving crop diversity, and of past to present perspectives to help understand contemporary diversity patterns.

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