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Measure of indigenous perennial staple crop, *Ensete ventricosum*, associated with positive food security outcomes in southern Ethiopian highlands

Nathan Morrow[a,**], James S. Borrell[b], Nancy B. Mock[a], Lucie Büchi[c], Andrea Gatto[d,e,*], Ermias Lulekal[f]

[a] *Tulane School of Public Health and Tropical Medicine, 1440 Canal St, New Orleans, LA 70112, United States*
[b] *Royal Botanic Gardens, Kew, Richmond, TW9 3DS, UK*
[c] *Natural Resources Institute, University of Greenwich, Chatham Maritime, ME4 4TB, UK*
[d] *Wenzhou-Kean University, Wenzhou, Zhejiang Province 325060, China*
[e] *Centre for Studies on Europe, Azerbaijan State University of Economics (UNEC), Azerbaijan*
[f] *Department of Plant Biology and Biodiversity Management, College of Natural and Computational Sciences, Addis Ababa University, P.O. Box 34731 Addis, Ababa, Ethiopia*

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ABSTRACT

Enset-based food systems are unique to southern Ethiopia where they serve as a staple food for millions of households. Enset, a banana relative of which the entire pseudostem and corm are edible, possesses a highly unusual combination of crop traits including perenniality, highly flexible planting and harvest times, and tolerance of a very wide range of environmental conditions, which together earn it the local name of "the tree against hunger." Previous studies have identified the strategic food security value of mature enset stands for household food security, but a multisector panel data set makes identifying wider enset food security associations tractable for the first time. We assess whether household data on area of mature enset is associated with four indicators of food security together with demographic, asset, and consumption covariates. We find that area of mature enset significantly improves estimates for three of four food security indicators, thus improving our understanding of the role of understudied indigenous crops. Consistent and reliable food security indicators are needed to improve monitoring, particularly with regard to stability. Variance components of multilevel longitudinal models indicate that exposure to both idiosyncratic and covariate disturbance affects food security stability in a way that is consistent with reports of enset acting as both a food security buffer and an active adaptation strategy in the face of shocks or change. Here we show that living assets comprising culturally relevant indigenous crops such as enset can improve accuracy of food insecurity assessments, which may encourage wider investigation of other agrifood system-specific asset-like natural stores of value associated with food security and resilience.

1. Introduction

Enset (*Ensete ventricosum (*Welw.) Cheesman) is the predominant starch crop for 20 million people in the southern highlands of Ethiopia, but it remains one of the least studied crops in Africa (Borrell et al., 2020). Enset is a giant perennial from the same botanical family as edible bananas (Musaceae), though enset grows taller and attains much greater biomass. Despite being botanically defined as herbs (lacking woody tissue), bananas are increasingly recognized alongside farm trees and tree-like perennials as making significant contributions to food security and nutrition (Miller et al., 2019, 2020). When mature, the entire plant of enset is destructively harvested, making enset somewhat harder to fit into an agricultural classification of trees on farms, where research tends to focus on trees that produce seasonal harvestable outputs (e.g., fruit and nuts). Although several small-scale studies and anecdotal information report enset systems to be drought-tolerant and essential to ensuring wellbeing and food security (Abebe and Bongers, 2012; Negash and Niehof, 2004; Quinlan et al., 2015), systematic quantitative

* Corresponding author at: Wenzhou-Kean University, Wenzhou, Zhejiang Province 325060, China.
** Corresponding author at: Tulane School of Public Health and Tropical Medicine, 1440 Canal St, New Orleans, LA 70112, United States.
E-mail addresses: nmorrow@tulane.edu (N. Morrow), j.borrell@kew.org (J.S. Borrell), mock@tulane.edu (N.B. Mock), L.A.Buchi@greenwich.ac.uk (L. Büchi), agatto@kean.edu (A. Gatto), ermias.lulekalm@aau.edu.et (E. Lulekal).

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investigations that model the association of enset with common household level measures of food security and nutrition are lacking.

Enset is a major asset to farmers because the entire vegetative pseudostem and underground corm is completely harvested at maturity, and this substantial biomass results in meeting adult caloric requirements with as little as 15 mature plants (Demeke 1986). The exact number of plants required varies among contextualized enset-based agricultural systems with dynamic and often farm-specific co-cropping strategies, cropping intensity, and factors affecting enset yields (Borrell et al. 2020). Research undertaken with Wolayita households in Ethiopia found that enset cultivation increased in reaction to farms becoming smaller (Dessalegn, 1995). Moreover, cultivation of ensets directly adjacent to a dwelling has been reported as contributing to food security for landless or effectively landless households (Brandt et al., 1997). These findings from an indigenous cropping system in Ethiopia may be germane to future food security challenges related to the declining smallholder farm size observed across Africa (Hazell 2020),

Wild enset is found throughout East and Southern Africa but has only been domesticated in the Ethiopian highlands (Borrell et al., 2019), where its central role in food security has earned it the moniker of “the tree against hunger.” Jeronimo Lobo, a 17th century Jesuit missionary, provided the first written description of enset in a European language, noting that “anyone that has one of these trees is not in fear of hunger” (Brandt et al., 1997; Lobo et al., 1640). Further evidence of the close connection between observed larger mature enset “trees” with food security status is reported by Habtewold et al. (1994), who found that the premature harvest of enset is a sign of acute hunger. Enset has a rare combination of advantageous agronomic traits (clonal propagation, flexible planting and harvesting times, perenniality) that support stable on farm staple food availability. Anecdotal evidence suggests that enset-growing areas were less vulnerable to the severe famines of the 1980s, and enset-based systems may offer multiple pathways towards resilient and sustainable food security (Dessalegn, 1995; Brandt et al., 1997). This is important in countries like Ethiopia in which indigenous agricultural systems are giving way to introduced crops that lack the advantageous attributes and genetic diversity of locally adapted indigenous crops (Khoury et al., 2014). A critical aspect of climate-smart resilient food systems is understanding the nature of indigenous crops’ contribution to food security that is in danger of being lost if it is not documented.

This paper aims to explore the relationship between enset cropping area, food security, and nutrition using panel data from the Ethiopia Socioeconomic Survey (ESS), a large multi-indicator household survey. We compared restricted and full regression models to investigate whether mature enset area provides additional explanatory power to standard variables such as assets (e.g., household items or productive farm implements), common consumption measures, or demographic indicators. The research addresses the following research questions: *Is mature enset associated with conventional measures of household food security? Does area of mature enset explain variation in food security status beyond regularly assessed drivers of food security and nutrition including assets, demographics, and consumption? Is enset cultivation associated with the availability, access, utilization or stability dimensions of food security? Do these associations vary locally?*

The paper is organized as follows: Section 2 examines the multidimensional roles of enset as a resilient and sustainable living asset for food security and resilience in rural Ethiopia. Section 3, Materials and Methods, presents the food and nutrition security indicators used in this study. We use a spatially informed hierarchical multilevel generalized linear mixture model over three waves of the ESS panel data to determine whether mature enset area is associated with common indicators of food security. Results are presented in Section 4. By comparing the relative association of enset with these indicators, reflecting the different dimensions of food security, we explore the asset-like qualities of the enset measurement and potentially other living green assets as indicators of food security and discuss limitations in Section 5. In Section 6, our conclusion summarizes the main results and next steps for research on enset and food security.

2. Association of enset with multiple dimensions of food security

Food security is a multidimensional concept that encompasses utilization, access, availability, and stability of food, typically measured by a suite of indicators at individual, household, and community levels (CFS, 2012). Staple crops and their associated indicators like production and yield are most closely associated with the availability dimension of food security. Enset has the highest biomass and food production per hectare of all crops in Ethiopia (Tsegaye and Struik, 2001; Kanshie, 2002; Borrell et al., 2020). Enset may also be associated with the access dimension of food security, which is measured by indicators of a household or individual’s entitlement to a sufficient and nutritious diet through purchases at the market or food produced at home. Although single plants or processed enset products may be sold in local markets, the majority is produced for household consumption (Borrell et al., 2020; Negash, 2001). Enset is also processed at home through a unique fermentation process that has been shown to provide important minerals like zinc and magnesium (Abebe et al., 2007, Tamrat et al., 2020). Enset porridges, which are rich in lactic acid bacteria (Ashenafi, 2006, Andeta et al., 2018), contribute to the utilization dimension of food security by improving pediatric gut health.

Perhaps the most unique contribution of enset to food security is its potential impact on stability. Enset’s function on the farm is described by Dessalegn (1995) as “strategic.” Once mature, typically within four years, enset plants can be harvested at any time; younger enset plants produce lower yields at harvest but can also meet needs in exigent circumstances. Processing enset into food products adds additional flexibility to its consumption. The harvested corm and pseudostem are pulverized and fermented for several months to improve palatability. Portions are then taken from the fermentation pit as needed over a period of months or even years (Tamrat et al. 2020; Borrell et al., 2020), providing a resilient, on-demand source of food. This capacity for asynchronous harvest allows enset to stabilize food system production and address seasonal food insecurity (Egli et al., 2020).

The presence of mature enset plants on a given farm has been identified in qualitative and anthropological studies as a culturally relevant indicator of wellbeing for the household (Olango et al., 2014), whereas a lack of sufficient mature enset plants is indicative of premature harvest and consumption to meet critical emergent or chronic ongoing needs, particularly for those with farms smaller than half a hectare (Habtewold et al., 1994). Olmstead (1974) using anthropological approaches reports that later harvesting of enset that is between 5 and 7 years old is socially desirable and indicates relative wealth. In the context of an agrifood system, the food security significance of mature enset area measurements may have immediate cultural resonance among farmers and other stakeholders in the southern Ethiopian Highlands.

3. Materials and methods

3.1. The Ethiopia Socioeconomic Survey

Although the literature on the contribution of enset to food security is compelling, the relationship between enset, food security, and nutrition has not yet been systematically analyzed at the household level. The Ethiopia Socioeconomic Survey (ESS), a large nationally and regionally representative household panel data set (Central Statistics Agency of Ethiopia and World Bank Group, 2017), is part of the Integrated Surveys on Agriculture initiative, supported by the World Bank and the Bill and Melinda Gates Foundation. It expands upon typical agricultural household surveys by encompassing a wide array of diverse rural livelihoods, assets, and strategies and including questions on trees and perennial crops, agricultural production, and socio-economic wellbeing outcomes at the national and regional levels (Carletto et al., 2015).

The ESS includes three waves of panel data collected by the Central Statistical Agency of Ethiopia in 2011–2012, 2013–2014, and 2015–2016 (Central Statistics Agency of Ethiopia and World Bank Group, 2017). The data used for this study is available from the World Bank Microdata site (https://microdata.worldbank.org, accessed January 15th, 2023) and is accompanied by extensive documentation of each survey campaign, survey instruments, and detailed information about the consumption indicators.

The ESS sample design provides a representative sample of households at the national level and for the Southern Nations Nationalities and Peoples Region (SNNPR), the geographical center of food systems based on enset. At the time of the panel survey, there were 73 rural Enumeration Areas (EAs) in the SNNPR (regional administrative boundaries for the SNNPR have changed since the three waves of data collection). Between wave one and wave three, less than 6% (n = 51) of 885 households were lost to follow-up or refused to participate. This figure was determined by the World Bank LSMS team to be minor and falls well below the 10% attrition rate commonly accepted by the research community as appropriate for analysis. We removed an additional seven households that did not meet CSA small farm size parameters (<five hectares). To create a balanced panel, 28 additional houses were removed due to missing data (CSA & World Bank, 2017), leaving our study with a sample size of 799 SNNPR households.

3.2. Description of the four food security indicators used as response variables

Four widely employed food security indicators were measured in a survey based on ESS household models, administered between December and January of each wave, after the harvest of annual crops. These serve as response variables in our analysis. Months of food insecurity (MINS) is a typical microeconomic indicator used in areas with seasonal hunger: Survey participants are asked to indicate which months in the previous year presented "a situation when you did not have enough food to feed the household."

Our study also used a modified Food Insecurity Experience Scale (FIES) to measure the UN's Sustainable Development Goal Target 2.1.2, "prevalence of moderate or severe food insecurity in the population." The FIES, which was developed as a Rasch model where each successive question is associated with more extreme food insecurity, is highly sensitive to short-term changes in the financial situation of poorer households. It comprises a series of eight questions beginning with "In the past 7 days, how many days have you or someone in your household had to rely on less preferred foods?" and concludes with "In the past 7 days, how many days have you or someone in your household had to go a whole day and night without eating anything?". Our implementation of the FIES by ESS differs slightly from Cafiero et al. (2018): We used a recall period of one week rather than one month, assessing each day as a separate data point, giving our FIES a range of 0–56.

The variable STUNT indicates children 6-59 months old experiencing linear growth failure, defined as < 2 standard deviations (SD) from the median length or height of the reference growth standards (WHO, 2023).

The Household Diet Diversity Score (HDDS) is a common household dietary consumption proxy indicator. For this analysis, we used the method proposed by Hoddinott and Yohannes (2002), grouping foods into a 12-category scale (staple cereals, protein-rich foods, vegetables, etc.) and counting the number of groups consumed by the household during the prior week. Table 1 provides a brief explanation of how the four indicators relate to the different dimensions of food security. The four food security indicators MINS, FIES, STUNT, and HDD were used as the response variables in four separate comparable regression models.

3.3. Area of mature enset as a potentially novel measurement related to food security status

We used ESS data to calculate the area of mature enset (MEnset), measured as hectares of enset more than 4 years old, for each surveyed farmstead. In most cases, plot-level measurements were obtained from global positioning system (GPS) data, so there is a high degree of confidence in these figures; farmer-estimated plot area measurements were used only when fields were inaccessible at the time of survey or too remote to be measured by GPS. MEnset as a novel measurement of food security is the primary explanatory variable of interest in this study.

3.4. Description of the asset, consumption and demographic explanatory covariates

Our analysis included seven additional variables to control for income and asset-related wealth measures and to isolate the MEnset-specific contribution to food security: 1) A measure of farm size in hectares (AgLand), calculated by adding together all cultivated, fallow, and pasture plots reported by ESS households without adding the area of mature enset that is included in the variable MEnset; 2) livestock data calculated as unidimensional Tropical Livestock Units (TLU) using a set of conversions provided by the Food and Agriculture Organization (FAO, 2023), with scripts adapted from the an LSMS-ISA agriculture indicator project by the University of Washington Evans School (EPAR, 2023); 3) consumption (Cons), the estimated total per-person value of everything purchased or produced by the households for members' own use measured in one thousand Birr units, calculated using rigorous regional price difference and between-wave inflation adjustments from the World Bank (CSA & World Bank, 2023); 4) female-headed households (FHH), a binary variable calculated from ESS data; 5) the total number of adults and children living in the household (HHSize); 6) an asset factor (HHobj) related to household and personal possessions such

Table 1
Relation between Food Security Dimensions and the four Food Security Indicators used in this study.

Food Security Indicator	Utilization	Access	Availability	Stability
MINS (Months of food INSecurity)		May indicate temporary food purchasing issues from loss of income or market failure	Typical measure of availability of food from own stores or markets	A measure of intra-annual variability in food security; particularly for measuring 'hungry season'
FIES (Food Insecurity Experience Score)		Food insecurity perception indicator considered as typical measure of access to desired level of food		Skipping meals and going one or more days without food are included as more extreme examples of food insecurity in this scale
STUNT (Household has at least one stunted child)	Anthropometry is a typical outcome measure of nutritional status			Stunting often occurs early in childhood and persists thus also reflecting food insecurity of earlier periods
HDDS (Household Diet Diversity score)	Associated with more nutritious diet	Associated with ability to access to a variety of food in the market	Associated with diversity of foods in the market or on farm from gardens and livestock production	

as blankets and mobile phones; and 7) a second asset factor (AgImp) related to agricultural implements such as axes, yokes, or plows. Assets, both personal and productive, are often counted in socioeconomic surveys, but these data must be transformed into unidimensional measures to be easily compared over time in a longitudinal analysis (Barrett et al., 2016; Naschold, 2012). We used factor analysis to reduce dimensionality on ESS data: Of the 34 household items and agricultural implements measured, 16 were selected that were owned by at least 1% of the population (for example, private cars and satellite television receivers were omitted since they were owned by only one or two households). Standard factor analysis using a default maximum variance rotation identified two orthogonal factors that accounted for > 95% of the variability in the asset data. Because the two factors were clearly related to either household possessions or agricultural tools in a population with little overall variation in types of assets, indices for these two asset categories were calculated without further rotation of factors.

3.5. Generalized multilevel linear model with random intercepts for nested panel data structure

We used a multilevel modeling approach to analyze food security indicators over the three waves of ESS panel data. The three-level variance components model improved estimation by modeling the nesting of observations in households and households in enumerations areas. This approach includes a random variance component at each level of the nested panel structure of the data to ensure that standard errors are not underestimated, test statistics accurately reflect strength of associations, and parameters are estimated efficiently (Wooldridge, 2010).

We also aimed to analyze associations of inherently multiscale food security indicators. An element of food security status may change rapidly due to an idiosyncratic shock to an individual or household, such as illness or serious injury. Location may also influence food security status. Covariate shocks from the market, effects of climate change, long-term structural stresses like health care access, and changes in food culture can all affect the association between enset and food security indicators at both household and cluster levels. Variance components associated with different food security response variable regressions can be compared in multilevel models to identify the relative importance of idiosyncratic and covariate errors.

Following Baltagi (2013) and Rabe-Hesketh and Skrondal (2008), random intercepts were included at third-level EA cluster ζ_j^3 and second-level household level ζ_i^2 to the three-level model of observations over three waves ($t_{1\text{-}3}$) of the ESS for households ($_i$) within enumeration areas ($_j$). MEnset is the explanatory variable of primary interest. All four models were extended to include other explanatory variables as covariates, including farm size (AgLand), livestock units (TLU), adult consumption (Cons), object assets (HHObj), agricultural implements (AgImp), female-headed households (FHH), and household size (HHSize).

A similar model was fit for each of the four food security indicators (MINS, FIES, STUNT, and HDD).

The models' form with the response variable (y) for MINS, FIES, STUNT, or HDD was regressed on explanatory variables and the random components as:

$$y_{ijt} = \beta_1 + \beta_2 MEnset_{1ijt} + \beta_3 AgLand_{2ijt} + \beta_4 HHSize_{3ijt} + \beta_5 FHH_{4ijt} + \beta_6 Cons_{5ijt} + \beta_7 HHObj_{6ijt} + \beta_8 xAgImp_{7ijt} + \beta_9 xHHSize_{8ijt} + \zeta_t^2 + \zeta_t^3 + \epsilon_{ijt}$$

where:

y_{ijt} is the response variable for food security status (MINS, FIES, STUNT, or HDD)

β_1 *is a constant offset*

β_{2-8} *are explanatory variable coefficients*

$\zeta_t^{(2)}$ *is a random intercept coefficient at household level*

$\zeta_t^{(3)}$ *is a random intercept coefficient at location level*

ϵ_{ijt} *is the observation level error component*

The type of variables and variance structure required specific distribution links in each of the four models. The Generalized Linear Mixed Effect models from the STATA 15 command library (StataCorp., 2021 p.86) were used for modeling response variables with the general formula:

$$\mathscr{g}\{E(\gamma|\mu)\} = X\beta + Z\mu, \gamma\ F$$

where

$\mathscr{g}$ is a link function for the distribution. $X\beta + Z\mu$ is the linear predictor describing the covariate matrix and the random intercepts in matrix notation. X is the covariate matrix for fixed effects β that is "analogous to the linear predictor from a standard OLS regression model with β being the regression coefficients to be estimated" (*StataCorp, 2021 p.9*). Similarly, Z is the covariate matrix for random effects μ. F is the distributional family that is selected based on nature and dispersion of the response variable.

MINS is a count variable (0–12) with overdispersed variance that was modeled with a negative binomial distribution as:

$$log\{E(\gamma|\mu)\} = X\beta + Z\mu, \gamma\ nbinomial$$

FIES (0–56) was developed as a Rasch model and therefore has characteristics of an ordinal response variable requiring an order logit approach:

$$logit\{E(\gamma|\mu)\} = X\beta + Z\mu, \gamma\ ordinal$$

STUNT (0–1) is a binary response variable and was modeled as:

$$logit\{E(\gamma|\mu)\} = X\beta + Z\mu, \gamma\ bernoulli$$

HDD (0–12) did not display variance overdispersion and was modeled:

$$log\{E(\gamma|\mu)\} = X\beta + Z\mu, \gamma\ poisson$$

Wald statistics estimate improved model fit, also referred to as reduction of deviance, from adding explanatory variables. Difference in explanatory power, or gain in prediction, is accurately estimated by the Wald statistic in large samples (Aiken et al., 2015). Most commonly used for assessing the fit of multilevel models, a 95% confidence interval for the Wald statistic is 1.96. We use this confidence interval of the Wald statistic to determine if adding area of mature enset improves model fit.

The data was analyzed with STATA 15 (Statacorp, 2017). The scripts used for processing, analyzing, and creating graphics from the ESS data are archived along with README files at a dedicated Github site (https://github.com/geografo-esploratore/green_assets, accessed January 15th, 2023).

4. Results

4.1. Descriptive statistics

The mean and standard deviation for four food security indicators in three ESS panel waves are presented in Table 2. The mean for months of food insecurity varied between 1.0 and 1.32 months across panel waves. Standard deviations for all indicators remained similar across panel waves for all four FS indicators. Stunting is measured at individual child level and the number of children 6–59 months in each panel wave is indicated below the stunting summary statistics.

Area measurements for mean farm size (AgLand) in hectares (hm^2)

Table 2
Food security indicators' mean and standard deviation in each ESS wave.

	Mean months of food insecurity MINS (std)	Mean food insecurity experience score FIES (std)	Proportion of households with stunted child(ren) STUNT (std) (# of HH with children 6-59 months old)	Mean household diet diversity score HDD (std)
Wave 1 (2011–12)	1.12 (1.79)	4.63 (6.81)	0.55 (0.50) (#585)	5.0 (1.54)
Wave 2 (2013–14)	1.32 (1.98)	3.12 (6.03)	0.50 (0.50) (#566)	4.95 (1.65)
Wave 3 (2015–16)	1.0 (1.7)	3.21 (5.32)	0.47 (0.50) (#518)	6.35 (1.74)

and enset cultivation descriptive statistics are presented in Table 3. The mean area of enset cultivation on farms was remarkably consistent across the three waves. Mature enset area was consistently lower in successive waves. At the same time, there was an increase in the number of households reporting enset plots.

Descriptive statistics for the explanatory covariates are presented in Table 4. The means tend to increase across waves for all variables except for the agricultural assets index and consumption.

Pearson correlations among continuous explanatory variables are presented in Table 5. MEnset was significantly correlated with all variables except consumption. The strongest correlation was between AgLand and TLU ($r = 0.54$), followed by a positive correlation between TLU and AGImp ($r = 0.39$).

Because FHH is a binary variable, point biserial correlations were performed for FHH associations with other explanatory covariates (Table 6). Point biserial correlations range from a perfectly positive to a perfectly negative correlation on a scale of 1.00 to -1.00. The strongest correlation indicated female-headed households to smaller household size (FHH-HHSize, $r = -0.33$). Female-headed households reported smaller area of mature enset, and fewer assets and livestock, all with negative coefficients of correlation.

4.2. Model results

The number of months with food insecurity (MINS) was regressed on MEnset with and without demographic, asset, and consumption covariates (Table 7). The negative coefficient indicated that MEnset was associated with reduced months of food insecurity. The MEnset coefficient was strongly significant, both alone and in the full model with other explanatory covariates ($p \leq 0.001$). TLU, Cons, and HHObj were negatively and significantly associated with months of food insecurity. FHH was significantly associated with longer periods of reported food insecurity. AgLand, AgImp, and HHSize did not have significant model coefficients.

Table 3
Mean and standard deviation of *farm size and areas devoted to enset/mature enset* in each ESS wave.

	Households growing enset/ total households	Area of AgLand in hm^2 (*std*)	Area of enset in hm^2 (std)	Area of mature enset in hm^2 MEnset (std)
Wave 1 (2011–12)	602/799	0.7373 (*0.7890*)	0.0593 (0.1210)	0.0410 (0.1163)
Wave 2 (2013–14)	651/799	0.8006 (*0.7789*)	0.0590 (0.0861)	0.0390 (0.0775)
Wave 3 (2015–16)	653/799	0.7609 (*0.8032*)	0.0582 (0.0964)	0.0330 (0.0651)

Covariate coefficients changed very little when MEnset was added to the model. Wald statistics indicated that MEnset provides additional explanatory information, predictive gain, above the more common food security-associated assets, consumption measures, and demographic indicators. The mean for the random intercepts at the EA location level was larger than the mean household random intercept, indicating that the differences in MINS between EA locations was larger than between households in the same location. This raises the possibility of more covariate processes driving the observed variability in MINS. The binomial overdispersion scalar was reported by the variance components model as Ln Alpha, and we saw an improved fit of the model with the addition of MEnset to the covariates, reducing Ln Alpha to near zero. The highly significant Wald statistic also improves with the addition of MEnset to the full model.

FIES was regressed on MEnset and the covariates with an ordered logit model (Table 8). Again, MEnset alone was significantly associated with improved food security and lower FIES ($p \leq 0.04$). Consumption, TLU, AgLand, HHObj were also significantly associated with lower FIES, as wealthier households are likely to experience less food insecurity. The coefficients for HHSize, FHH, and AgImp were not significant. The coefficient estimates and standard deviation for most covariates remained unchanged when MEnset was added to the full model. The Wald statistic indicated that adding MEnset to the model increased predictive gain through better model fit by more than the 95% confidence interval. A pattern similar to the results of the MINS model of higher variability between EA locations was reflected in the multilevel variance components for the FIES model. When FIES was regressed only on MEnset, more variability between households was observed than when all covariates were included.

The indicator related to the presence of stunted children STUNT was regressed on MEnset and covariates with a logit model (Table 9). Because stunting is measured at individual level for children 6–59 months of age, the sample size for this regression is only the 531 households that had a total of 1669 child measurements over the three panel waves. Coefficients for TLU and HHObj assets were the only explanatory variables with significant associations to stunting other than area of mature enset. The full model for STUNT also showed little change in the coefficients or standard deviation of the covariates when MEnset was added to the model, indicating that MEsent had an independent association with STUNT. Between-household variation was relatively more important in the STUNT models, with a mean random intercept of almost double that of the EA location cluster component. The Wald statistics were significant, and the highest Wald statistic indicated the best fit for the full model.

Household diet diversity (HDD) had a much lower standard deviation than other food security response variables and was therefore regressed on the covariates with a Poisson distribution. The coefficient of MEnset was not significant alone or in the full model (Table 10). HDD varied relatively little across waves, between locations, or between households as reported in the variance components. This was reflected in the highly significant and consistent $ß_1$ intercept.

5. Discussion

5.1. Potential of MEnset as an indicator for multidimensional food security

Despite economic growth and indications of improved child nutrition, food insecurity persists for millions of Ethiopians, particularly in rural areas (Sisha, 2020). Dessie et al. (2022) found that strong residual subnational spatial patterns of household level food security remain even after controlling for variation in primary drivers of food insecurity, such as lack of assets, high dependency ratios, and shocks. Their findings suggest that unknown but locally important variables could help explain geographic differences in food security status. Enset is widely regarded

Table 4
Mean and standard deviation of the *demographic, consumption, and asset covariates.*

	Female headed household FHH (std)	Household Size HHSize (std)	Consumption per Adult Equivalent Cons (std)	Tropical Livestock Unit TLU (std)	Household assets index HHObj (std)	Agricultural assets index AgImp (std)
Wave 1 (2011–12)	0.21 (0.4)	5.17 (2.28)	4960 (5913)	1.62 (1.62)	0.72 (0.62)	0.83 (0.59)
Wave 2 (2013–14)	0.22 (0.42)	5.74 (2.34)	4308 (3268)	1.85 (1.61)	0.82 (0.79)	0.70 (0.52)
Wave 3 (2015–16)	0.23 (0.42)	6.14 (2.4)	4741 (4812)	1.95 (1.85)	0.88 (0.78)	0.47 (0.47)

Table 5
Pearson correlation coefficients of MEnset and other covariates.

	MEnset	AgLand	HHsize	Cons	TLU	HHObjs	AGImp
MEnset	1.0						
AgLand	0.21***	1.0					
HHSize	0.13***	0.26***	1.0				
Cons	0.01	−0.03	−0.21***	1.0			
TLU	0.17***	0.54***	0.32***	−0.03	1.0		
HHObj	0.15***	0.16***	0.16***	0.16***	0.16***	1.0	
AGImp	0.07***	0.36***	0.25***	−0.03	0.39***	0.16***	1.0

**** p ≤ .001, **p* ≤ .01, *p ≤ .05.

Table 6
Point biserial correlation coefficients between FHH and MEnset and other covariates.

	MEnset	AgLand	HHsize	CONS	TLU	HHObj	AgImp
FHH	−0.06*	−0.14*	−0.33*	0.1*	−0.13*	−0.1*	−0.15*

**** p ≤ .001, **p* ≤ .01, *p ≤ .05.

Table 7
MINS regressed on MEnset and demographic, asset, and consumption covariates.

MINS	MEnset only (standard error)	Covariates only (standard error)	MEnset & Covariates (standard error)
β_1 (std error)	−0.33*(0.17)	0.12 (0.20)	0.16 (0.20)
MEnset	−4.77*** (0.80)		−3.09*** (0.81)
AgLand		0.09 (0.007)	0.07 (0.07)
FHH		0.27** (0.09)	0.26** (0.09)
HHsize		0.03 (0.02)	0.03 (0.02)
Cons		−0.02*** (0.008)	−0.02*** (0.008)
TLU		−0.19*** (0.03)	−0.18*** (0.03)
HHObj		−0.44*** (0.09)	−0.42*** (0.06)
AgImp		−0.06 (0.09)	−0.05 (0.09)
Random part			
Ln Alpha	0.24 (0.07)	0.02 (0.08)	>0.01 (0.08)
EA intercept	1.80 (0.38)	1.83 (0.39)	1.74 (0.37)
Nested HH intercept	>0.01 (>0.01)	>0.01 (>0.01)	>0.01 (>0.01)
Fit			
Wald	35.77***	173.50***	187.5***

**** p ≤ .001, **p* ≤ .01, *p ≤ .05.

Table 8
FIES regressed on MEnset and demographic, asset, and consumption covariates.

FIES	FIES only (standard error)	Covariates only (standard error)	FIES & Covariates (standard error)
MEnset	−2.84** (0.91)		−2.01* (0.96)
AgLand		−0.28** (0.09)	−0.27** (0.09)
FHH		0.21 (0.12)	0.21 (0.11)
HHsize		−0.01 (0.02)	−0.01 (0.02)
Cons		−0.05*** (0.01)	−0.05*** (0.01)
TLU		−0.18*** (0.05)	−0.17*** (0.05)
HHObj		−0.56*** (0.08)	−0.55*** (0.08)
AgImp		−0.02 (0.11)	−0.02 (0.11)
Random part (standard error)			
EA intercept	1.15 (0.09)	1.29 (0.07)	1.31 (0.08)
Nested HH intercept	−0.21 (0.25)	>0.01 (0.13)	>0.01 (0.13)
Fit			
Wald	9.78**	153.91***	156.48***

**** p ≤ .001, **p* ≤ .01, *p ≤ .05.

as a regionally important food security staple among communities in southern Ethiopia. Using multiple waves of panel data, we show that including the area of mature enset as an explanatory variable improved the regression model fit for three out of four food security indicators.

The largest model fit improvement with the inclusion of MEnset, indicated by the Wald statistic, was for months of food insecurity (MINS), followed by STUNT and FIES. The HDD model showed only slightly improved fit for the full model over the restricted model that was smaller than the Wald statistic confidence interval. Menset alone was significantly correlated to MINS, FIES, and STUNT. The coefficient for MEnset remained significant in the full models that included demographic, asset, and consumption explanatory variables. Further confirming the additional explanatory power of MEnset, the comparison of a restricted covariate-only model with a full model including MEnset maintained the consistency of coefficients for the explanatory covariates. A significant association of MEnset with HHD was not supported by the model. This result is somewhat unexpected, given that previous studies have recorded a diversity of horticultural crops and livestock common to enset agrifood systems (Abebe, 2013). Dietary diversity as measured by HDDS, with broad categories for staples, animal products, and vegetables, would not capture this more nuanced level of onfarm diversity.

A key attribute of enset systems is that they display overlapping generations of individuals, as opposed to cereals which consist of a

Table 9
STUNT regressed on MEnset and demographic, asset, and consumption covariates.

STUNT	STUNT only (standard error)	Covariates only (standard error)	STUNT & Covariates (standard error)
β_1	−1.03 (0.12)	0.36 (0.28)	0.37 (0.28)
MEnset	−2.56** (0.97)		−1.79* (0.90)
AGland		−0.08 (0.11)	−0.12 (0.11)
FHH		−0.31 (0.23)	−0.28 (0.24)
HHsize		−0.04 (0.04)	−0.04 (0.04)
Cons		−0.01 (0.01)	−0.02 (0.02)
TLU		−0.27*** (0.06)	−0.27*** (0.06)
HHObj		−0.31** (0.11)	−0.28** (0.11)
AgImp		0.29 (0.15)	0.27 (0.15)
Random part (standard error)			
EA intercept	0.65 (0.12)	0.62 (0.11)	0.64 (0.12)
Nested HH intercept	1.08 (0.12)	0.96 (0.12)	0.97 (0.12)
Fit			
Wald	6.94**	39.06***	42.28***

*** $p \leq .001$, **$p \leq .01$, *$p \leq .05$.

Table 10
HDD regressed on MEnset and demographic, asset, and consumption covariates.

HDD	HDD only (standard error)	Covariates only (standard error)	HDD & Covariates (standard error)
β_1	1.68*** (0.2)	1.45*** (0.05)	1.45*** (0.04)
MEnset	0.18 (0.11)		0.03 (0.11)
AgLand		0.2 (0.02)	>0.01 (>0.01)
FHH		−0.03 (0.02)	−0.03 (0.02)
HHsize		0.01* (>0.01)	0.01* (>0.01)
Cons		0.02*** (>0.01)	0.02*** ((>0.01)
TLU		0.02* (0.01)	0.02* (0.01)
HHObj		0.09*** (0.01)	0.09*** (0.01)
AgImp		−0.02 (0.02)	−0.02 (0.02)
Random intercepts (standard error)			
EA intercept	0.02 (0.01)	0.016 (>0.01)	0.016 (>0.01)
Nested HH intercept	>0.01 (>0.01)	> 0.01 (>0.01)	> 0.01 (>0.01)
Fit			
Wald	2.83	189.85***	189.90***

*** $p \leq .001$, **$p \leq .01$, *$p \leq .05$.

single demographic age class harvested before a new generation is sown. This means that monitoring MEnset can be associated with household food security status in a way analogous to a statistical moving average. Beyond cultural preference for an optimal age of maturity, enset growth is not linear with much greater biomass accumulation after a typical third year transplantation (Tsegaye, 2007). Early harvesting over consecutive years will lower the mean age of the enset stand, lower yield, and eventually reduce the number of fully mature enset plants. A key limiting factor for enset production is the availability of fertilizer, typically in the form of cow manure (Scoones, 2010). Other things being equal, an on-farm enset garden would be as large as fertilizer access allows, and any household with smaller areas of mature enset would be expected to either have fewer livestock or to have harvested early while experiencing one or more dimensions of food insecurity. While fewer livestock may indicate relative poverty, which can increase vulnerability to access-related food insecurity, our results indicate that MEnset is also specifically sensitive to the availability and utilization dimensions of food security.

The availability dimension of food security measured as months of food insecurity (MINS) was strongly associated with MEnset; that is, a larger area of mature enset was associated with fewer months of food insecurity. This is consistent with the documented role of enset as both a staple food and a strategic asset. MINS is highly sensitive to annual "hungry" periods typical of annual cereal-based subsistence systems with recurrent low availability and high prices for staples. These cyclical covariate periods of stress affect entire communities at the same time, as reflected in the relatively high explanatory power of the random intercept for variation between locations in MINS regression. Households with enset gardens can reduce the impact of this covariate intra-annual variability by relying on stores of available calories and an ongoing stream of fodder to maintain livestock throughout the year (Brandt et al 1997). An average increase by one standard deviation in mature enest would reduce the mean period of food insecurity by 6–11 days (23%–42%).

Area of mature enset is also associated with indicators of the utilization and access dimensions of food security. The pattern of covariates and variance components indicated by child malnutrition suggests that different utilization dimension processes may drive the modeled association between enset and stunting. This expected importance of intra-household dynamics is reflected in the random intercept for between-household variance, which was much larger for STUNT compared to the three other indicators of food security. Limited financial or physical access to markets is likely to impact these components of the food insecurity experience score more than mature enset. The explanatory variables related to consumption and assets, as well as the random intercept for location, explain much of the variance in the model for FIES representing the access dimension. An average increase by one standard deviation in mature enest, depending on the panel wave, is expected to reduce stunting by 2.1% − 6.62% and FIES score by 0.43–1.06 (13%–23%).

The stability dimension is typically described by changes in indicators related to the other food security dimensions over time rather than a dedicated stability indicator. MEnset provides a compelling case for agrifood system-specific indicators that may be more directly associated with stability through a buffering function. Habtewold (1994) describes a straightforward mechanism in which households under acute food stress simply consume or sell all their standing enset before it reaches maturity. Further research is needed to see if this phenomenon shares similarities with distress sales as described by Hoddinott (2006).

Going beyond buffer-related stability, increasing MEnset may indicate an active resilience-focused adaptation strategy. Chase et al. (2023) found that farmers expanded enset cultivation following severe droughts that negatively affected annual crops. Olmstead (1974) describes communities that had given up grain farming completely for other income-generating livelihood activities but kept a reserve of enset to guard against food insecurity risk. Lack of enset in enset-growing areas may indicate reduced stability and resilience. Some communities have reported that transition out of enset cultivation undermined both household food security and environmental resilience, leading to longer-term vulnerability and wellbeing loss despite a short-term increase in monetary income (Quinlan et al., 2015).

Measuring food insecurity with standard measures across contexts has remained elusive for decades (Barrett, 2010), and the disparity between food security indicators has become more obvious with better data collection and uneven economic development (Poudel and Gopinath, 2021). Food security indicators tend to be focused on one dimension of food security, borrowed from a specific disciplinary tradition, and lacking a unidimensional or comprehensive measure of food security at individual, household, or aggregate levels. Investigating traditional and understudied crop systems with respect to food security involves exploring resilient farmer strategies for food security that often rely on low-input or nature-based solutions. Barrett et al., (2016) noted the overarching importance of the class of assets associated with natural capital and the associated biophysical mechanisms foundational to rural livelihoods and concluded that natural asset-based studies have been "strikingly thin." Since the contribution of roots, tubers, bananas, and enset remains difficult to quantify, availability-focused food security measures tend to limit themselves to cereal-based staples although other crops are increasingly important to achieving the zero-hunger SDG (Petsakos et al., 2019). On-farm research in agrifood systems outside of enset-growing areas may provide additional examples of crops with enset's asset-like properties and natural storage solutions. Reform is desperately needed to improve measures of food security indicators, particularly for indigenous agrifood systems. A recent paper in the journal *Nature* by Park et al., (2023) suggest that scientists should read more widely and engage in more interdisciplinary investigations to move forward with innovations that may disrupt the unsatisfactory stasis in research areas such as food security measurement.

5.2. Study limitations

Because we analyzed data that was not collected to meet the specific objectives for this study, our options were limited. The ESS data for quantifying harvested enset was not collected in the first survey wave and faced technical challenges in subsequent waves (CSA & Worldbank, 2017). The practice of storing post-harvest enset in fermentation pits, which seems to improve child health and serves as an important source of food security, was not measured during the surveys. This restricted our analysis to area-based measures of enset plots that were quality checked and collected with standard technologies and approaches. The CSA and Worldbank teams also note persistent challenges with local measures that may lower the reliability of the consumption indicator despite increasingly detailed approaches in successive waves of the ESS. Approaches to collecting food security indicators are often not standardized: In our study, the food security indicator FIES was collected with a non-standard recall time and a scale from 0 to 56 rather than the more common 0–8. These variations suggest that improving measurements of other crop asset and storage metrics in future survey efforts could proceed with more standardized measurement methodology and potentially more technology-supported data collection, such as digital imaging or remote sensing.

A great deal remains unknown about enset agrifood systems. The appropriate covariates to capture gender or cultural aspects of food security association with enset likely go beyond female-headed households or household size. Age and experience are required for a thorough cultural knowledge of enset propagation and processing, and understanding of the gendered roles in maintaining an enset garden would likely provide insight. The regression relationships used in this study do not allow for causal inference. Causal explanation of the observed relationship will require many more investigations into the complexity of potential food security pathways apparent in the enset agrifood system using causal research designs and methods.

6. Conclusion

Research on enset-based agricultural systems has grown substantially in recent years as interest in indigenous resilience strategies has increased (Altieri et al., 2015; Koch et al., 2022). This study provides evidence of the association of enset with a multidimensional set of food security indicators among rural farmers in southern Ethiopia. Because agricultural survey systems and food security studies do not often prioritize capturing the value of indigenous and understudied crops like enset, essential sources of food security and resilience may be overlooked. While a causal explanation of the observed relationships will require further investigation, our analysis has shown that an indicator focused on area of mature enset is significantly correlated with food security status.

MEnset improved the fit of models for three of four commonly collected food security indicators. Consistent with the literature, enset may play an asset-like role that smooths consumption to reduce periods of food insecurity. In the model where the presence of stunted children was regressed on mature enset area and covariates, random components explained more variation between households, rather than between locations as was the case for the three other food security measures. This may indicate a relationship between enset and both covariate and idiosyncratic disturbances in modeled food security. Stability-focused food security indicators are understudied. Measures of agrifood systems that include culturally relevant indicators such as MEnset may improve understanding across multiple dimensions of food security and more accurately identify determinants of stability.

Much remains to be studied about the role of enset and other permanent crops and living stores of value. Promising future avenues of investigation are abundant and include the comparative impact of drought and other hazards on enset-related food security resilience capacities. Little is known about the interactions among age, gender, and vulnerability status with enset's association with food security. Unpacking enset's contributions to different composite indicators such as household diet diversity would help to determine whether enset is only a substitutable starch or a source of more complex nutrition or resilience qualities. More direct observation of enset maturity, and quantification of mature enset by remote sensing, is also a promising line of future research. More detailed investigations of how to measure diversity in mixed enset cropping systems is needed. Broader investigations may identify a range of permanent crops or other living stores of value that may play a similar asset-like role in smoothing consumption with natural or green food storage capacities improving farmer food security as reported here for enset.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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