Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 46 No. 6
June 2025

Effect of Enset Production on Food and Nutrition Security in Densely Populated Communities of Wolaita and Kembata Zones in South and Central Ethiopia

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Abstract

Enset cultivation is uniquely positioned as the major strategic crop capable of addressing food availability, cess and stability challenges among the densely populated commodity-producing communities in the Wolaita and Kembata zones. Celebrated for its climate resilience, adaptability, high productivity, cost-effectiveness, and social importance, Enset emerges as a crucial solution for enhancing daily energy intake among producers. This study, therefore, seeks to examine the causal relationship between the amount of Enset harvested and the food and nutritional security of farmers in Southern and Central Ethiopia. Data were gathered from 374 households across the targeted zones through a structured survey. To assess causal effect of Enset production on food and nutrition security, the study employed the Generalized Propensity Score (GPS) method using a multilevel treatment framework. Household calorie intake served as a proxy indicator for food and nutrition security, while the quantity of Enset harvested over the past year represented the level of Enset production. The findings reveal that smallholder farmers engaged in an optimal lower level of Enset harvesting for food experienced a significant increase in their daily energy intake. The regression adjustment results further confirmed that enabling smallholder farmers to diversify their sources of consumption, including both market purchases and their own production, enhances food and nutrition security. This emphasizes the importance of Enset cultivation to improve and balance household energy consumption in Southern Ethiopia. The study's findings underscore the importance of maintaining optimal lower levels of Enset harvesting as a sustainable approach to improving food and nutrition security among farming communities in the commodity-producing regions. Additionally, the study revealed that a higher number of Enset harvests does not necessarily lead to increased consumption of Enset-based food items. Instead, it suggests that some of the harvest is allocated to other household needs, highlighting the need to integrate the Enset food system with other food crops for more comprehensive food and nutrition security.

Keywords: Daily energy intake, causal relationship, production, and Generalized Propensity Score.

1. Introduction

Enset is grown by over 6.6 million farmers in Ethiopia, covering around 390,208 hectares nationwide (CSA, 2022). Although it holds significant potential, Enset remains an underutilized yet resilient staple starch crop, presenting considerable opportunities both within Ethiopia and internationally (Borrell et al., 2019). With an average dry matter yield of 20 kg per plant, total production exceeds 4.13 billion metric tons. Challenges such as inadequate extension services, lacking genetic conservation strategies, and awareness problems regarding its values and effect on food problems have contributed to its underutilization. Nevertheless, Enset demonstrates exceptional capacity to sustain food security at the family level and mitigate household food shortages, surpassing that of other crops (Shumbulo et al., 2012; Awol et al., 2014; Asfawu, 2017).

Enset cultivation covers approximately 390,208 hectares of land, accounting for 3.74% of the total agricultural land area in Ethiopia, which is 9.61 million hectares. This places *Enset* as the eight most cultivated crop in the country, trailing behind *Teff*, wheat, sorghum, maize, coffee, barley and horse bean.

Remarkably, Enset stands out as the 2nd crop to maize being cultivated by the largest number of smallholder farmers nationwide, with over 6.6 million farmers involved in its cultivation. Additionally, Enset holds the top position in terms of being cultivated by the highest number of smallholder farmers and in the preservation of indigenous seeds, underscoring the need for development, research, and scientific collaboration. Despite its popularity among Ethiopian farmers, Enset cultivation receives minimal policy support and developmental efforts (CSA, 2022).

Enset plays a vital role as a food security crop, primarily grown for human consumption. It significantly contributes to enhancing food security within its cultivation areas, yet there is a pressing need to enhance its production. Addressing the current supply-demand gap is imperative to meet the escalating demand and ensure food availability, access, utilization, and stability, especially in light of population growth (Robert *et al.*, 2015; Ibsa *et al.*, 2019; Blomme *et.al.,* 2023).

Enset farming is well-known for its high content of carbohydrates, ash, and fiber, though it has relatively low levels of protein and fats. The corm of Enset contains 17 out of 20 amino acids, with concentrations of 12 amino acids matching or exceeding those found in potatoes. The main food product derived from Enset is **kocho**, a starch-rich food produced by processing and fermenting the plant's pseudo-stem and corm. The pseudo-stem is rich in soluble carbohydrates (80%) and starch (65%), though it contains relatively low levels of protein (4%). Enset-based foods are also notable for their high mineral content, including calcium, potassium, and zinc. Enset also serves as a valuable source of essential amino acids such as lysine and leucine and key minerals like calcium and potassium (Mohammed et al., 2013; Abraham et al., 2016; Solomon and Satheesh, 2019).

Enset cultivation is a significant foodstuff commodity known for its optimal carbohydrate content nevertheless relatively low levels of vitamins with proteins. Cultivating sufficient Enset plants in the fields of smallholder farmers helps ensure that households do not suffer from hunger. Enset-based households are positioned one step ahead of non-producers in terms of daily energy intake and access to a stable diet at a low cost (Jacobsen *et al*, 2018).

The *Kocho* yield derived from Enset outperforms other major food and cash crops cultivated in Ethiopia in both temporal and spatial dimensions, particularly regarding edible dry weight and energy production. Integrating Enset cultivation with root and tuber crops offers substantial benefits, supplying affordable energy to communities, especially in densely populated regions with minimal input needs. This approach promotes sustainable resource utilization among the population (Admasu and Struik, 2001).

The Enset crop in Ethiopia holds significant potential for addressing food and nutritional challenges, playing a vital role in ensuring nationwide food, availability, access and stability. It is also acknowledged as a crucial crop for achieving the United Nations Sustainable Development Goals, especially those focused on ending hunger, ensuring food security, and enhancing nutrition by 2030.Supporting Enset cultivation across various regions is crucial for enhancing food and nutrition security, especially among impoverished and marginalized populations. Enset stands out as the only crop in both area of cultivated and domesticated in the country, embodying cultural, economic, and nutritional values while contributing to food availability, access, utilization and stability (Selamawit et al., 2021; Teshome et al., 2022).

Enset holds top rank for being the primary crop in terms of indigenous seed holders in Ethiopia. Alongside coffee, Ethiopian cabbage, and banana, it ranks among the top five crops in this regard.The number of indigenous seed holders ranks as follows: maize leads with 7,131,546, followed by Enset with 6,601,036, coffee with 6,451,683, teff with 6,326,284, and Ethiopian cabbage with 4,513,656. In Southern Ethiopia, approximately 3,440,814 farmers cultivate Enset, covering about 189,594 hectares of land. Among these, 4,037,151 are indigenous seed holders, covering an area of 244,361 hectares. These figures underscore the widespread cultivation of Enset among farmers, indicating its preference over other crops due to its food and nutritional value, climate resilience, and various values (CSA, 2022).

Enset stands out as the top-ranking climate-smart solution and an effective remedy for hunger due to its remarkable resilience to prolonged drought, superior yield, energy provision, and cost-effectiveness. However, despite these advantages, the development policy focus on this commodity remains inadequate, hindering its optimal utilization. Several factors contribute to the limited cultivation and underutilization of Enset, which remains largely restricted to the southwestern region of Ethiopia. These challenges include cultural attitudes, political influences, historical circumstances, and a lack of adequate research and development (Gezahagn et al., 2022).

Table 1. Major staple food crops and their cost of energy yield

Major Staple Food Crops	*Yield Per Ha*	*Price Per Quintal*	*Energy Obtained (Kcalorie) Per Kg*	*Total Energy Yield Per Ha*
Enset	750	3500	2110	1582500
Taro	272.43	1200	3620	986196.6
Sweet Potato	228.79	1400	3510	803052.9
Potato	166.87	1500	3160	527309.2
Maize	41.95	3000	3560	149342
Wheat	31.11	4700	3550	110440.5
Barley	25.93	6000	3723	96537.39
Teff	19.14	7500	3580	68521.2

Source: own calculation household survey data and CSA, 2022

The table highlights that root and tuber crops are the most economical, cost-effective, and efficient energy sources for farming communities, emphasizing the need for policy support to enhance their development and utilization. Among these crops, Enset is found to be the most cost-effective food commodity consumed in Ethiopia, underscoring the need for strong policy support in research and development. As noted by Admasu and Struik (2001), Enset ranks highest in the country for kocho yield per unit area and time, in terms of edible dry matter and energy production. Compared to other major staple crops, Enset provides greater yields of dry matter and energy. Integrating Enset and other root and tuber crops with vegetables and pulse crops in densely populated, low-input farming systems can significantly enhance both food security and ecological sustainability.

Expanding the cultivation of underutilized Enset crop can greatly improve the diversity and resilience of global agricultural systems in response to climate change. As a climate-resilient crop, Enset holds significant potential for addressing food and nutrition insecurity beyond the regions where it is currently grown (Koch et al., 2021).

Eliminating food and balanced nutrient shortage and ensuring adequate energy intake are primary strategies and overarching goals of the Ethiopian government. Currently, shortage in food access, availability and stability has emerged as a major policy challenge and a growing concern in the developing country. The food production and security status of farming communities in the *Wolaita* and Kembata zones largely hinge on the level of Enset harvesting for consumption. Enset, known for its climate-smart, productive, and adaptable characteristics, plays a crucial role in supporting the food system for rural households in these districts. Despite Enset's numerous economic, social, and environmental benefits, it has received limited policy support, largely due to an information gap regarding its causal relation of its production to daily energy intake.

One of the key advantages of Enset cultivation is its support to ensuring daily energy intake. Therefore, cultivating this particular crop can lead to improved energy intake and enhance food security for all individuals. The food assistance provided by the Enset crop significantly influences household food security and optimizes nutrition levels. To address the information gap and generate relevant knowledge, it is essential to conduct a study on the causal relationship between Enset production levels and energy intake. Accordingly, this study aimed to investigate the causal effect of quantities of Enset harvesting on daily energy intake of the commodity producer communities.

2. Literature Review

This section outlines the theoretical and conceptual frameworks for impact evaluation, examines the extent of Enset cultivation and consumption, explores daily energy intake and analyses the causal effect of Enset production on the daily energy intake of households that cultivate it.

2.1. Theoretical Review of Impact Evaluation

The Impact evaluation carried out by constructing a comparison group and building the counterfactual by approaches of randomization, difference in difference, regression and discontinuity and matching. Matching can be undertaken by pipeline comparisons and Propensity score. Impact evaluations of policy interventions can be conducted either prior to their design or following their implementation, with the aim of enhancing learning and strengthening the accountability of public policies.For undertaking the econometric evaluations and fined the estimation of average treatment effects constrained by time, resource and data rely on theory based evaluations (Pattanayak, 2009).

The Double Difference (DD) Impact Evaluation method evaluates program effects using panel data collected through a baseline survey conducted before the program's implementation and a follow-up survey carried out after the program has been in place for some time. These surveys must be consistent in terms of questions and methodology and should include both program participants and nonparticipants. This approach helps control for bias from unobserved variables, assuming these variables remain unchanged over time. The DD method estimates the change in consequences between treatment and comparison groups in the post-intervention period, relative to the differences observed at baseline. It is especially effective for longitudinal or repeated cross-sectional data and offers a more accurate measure of a program's impact (Richard and Monica, 2000; Khandker et al., 2010).

Randomization Impact Evaluation is most effective when households are randomly allocated to the treatment group, as this approach eliminates selection bias. By ensuring that any differences between the treatment and control groups are not systematic, random assignment allows for a reliable comparison of outcomes. When properly designed and implemented, randomized evaluations yield unbiased estimates of a program's impact within the sample. This method is often illustrated using a top-down framework, which connects program placement with individual participation (Khandker et al., 2010).

The Propensity Score Matching (PSM) technique is a non-parametric approach developed to address challenge in identifying the impact of treatment on outcomes. It does not require specific assumptions to be made and can be combined with other techniques to produce more accurate estimates while allowing for less restrictive assumptions (Richard and Monica, 2000). PSM is particularly useful for conducting area-level impact evaluations and public project assessments. Its use adds value to these evaluations by allowing for objective and quantitative selection of the most suitable control areas in case series and quasi-experimental designs (F. de Vocht et al., 2016).

The core idea of Propensity Score Matching (PSM) is to pair each participant with a comparable nonparticipant and then assess the average difference in outcomes between the two groups. PSM estimates the likelihood of each household receiving the treatment and tests the balancing property, which ensures that households with similar propensity scores share comparable observable characteristics, regardless of whether they received the treatment. Once balance is confirmed, different matching techniques can be applied to estimate the average treatment effect.

PSM is designed to reduce bias by selecting treatment and comparison groups based on observable characteristics. It is typically implemented after a program has been in operation for some time and survey data have been collected. This method is considered a dependable approach for analyzing nonrandomized, observational data and for controlling potential confounding variables (Steven and David, 2018).

The trend of propensity score matching application in high quality studies is increasing over times. In application of PSM the application of sensitivity analysis helps to evaluate effect of unmeasured confounder on the outcome of the semi-parametric approach. It was deemed suitable for longitudinal data involving a group of low-income homeowners, with comparisons made to a group of renters. Propensity Score Matching (PSM) models are known to produce unbiased estimates and effectively address selection bias (John et al., 2003; Michal et al., 2014).

Propensity Score Matching was used to perform an ex-post impact evaluation of the adoption of improved groundnut varieties on crop income and rural poverty. It also served to examine the links between poverty, food security, and climate change using cross-sectional data. The study's findings suggest that the results are not affected by unobserved selection bias and can serve as a useful reference for policy-making (Kassie et al., 2010; Cecilia, 2013).

The Propensity Score Matching model found to yield reliable information from impact of climate-smart agricultural practices on the welfare of rural households, the effect of Moringa cultivation on household daily energy intake, and the influence of training at farmers' training centers on household farm income, using cross-sectional survey data. The study's results demonstrated well-balanced, efficient, and unbiased covariates (Muluken et al., 2017; Alula et al., 2020).

Quasi-experimental impact evaluation is a research design used to test causal relationships. Similar to randomized controlled trials, it treats the program as an intervention, with the "treatment" representing the policy components under evaluation. Key methods for establishing a valid comparison group in this approach include regression discontinuity design and propensity score matching (Howard and Shagun, 2014).

The generalized propensity score (GPS) is used for estimating non-binary treatment regimes, such as continuous treatment. GPS is preferred for its robustness and suitability in estimating the full dose-response function, rather than just the average treatment effect. It generalizes propensity scores by improving the robustness of the propensity function (Michael and Alessandra, 2007; Shandong et al., 2020).

The Generalized Propensity Score (GPS) is used to estimate treatment effects in contexts involving non-binary or continuous treatments. It is preferred for its robustness and its capacity to capture the full dose-response relationship, rather than just the average treatment effect.By extending the traditional propensity score framework, GPS enhances the reliability of the propensity function in more complex treatment scenarios (Michael and Alessandra, 2007; Shandong et al., 2020).

The Generalized Propensity Score (GPS) enables the estimation of a continuous dose-response function, which associates each level of treatment exposure (e.g., the quantity of treatment received) with the corresponding outcome. This method adjusts for covariate imbalances in continuous treatment settings before estimating the dose-response relationship. GPS extends traditional propensity score techniques to accommodate quantitative exposures, such as the amount of Enset harvested in this study. It is also used to evaluate the impact of continuous exposures on survival or time-to-event outcomes. Findings from GPS-based dose-response estimates have demonstrated minimal bias (Jochen et al., 2012; Peter, 2019).

The Generalized Propensity Score (GPS) approach has proven effective in a range of applications, such as assessing the welfare effects of smallholder farmers' participation in the Moringa market, estimating the impact of improved sheep breed adoption on household income, and evaluating the effect of nutrient levels on stream invertebrates using cross-sectional survey data (Solomon et al., 2015; Ouyang et al., 2018; Tezera et al., 2020).

The semi-parametric estimator for binary outcomes is particularly effective for addressing endogenous regressors and is well-suited for estimating the impact of nonfarm income on technology adoption decisions. This GPS-based estimator assumes that the endogenous variables are continuous and follows a two-stage procedure. In the first stage, the endogenous variables are regressed on instrumental variables and other exogenous factors. The resulting residuals are then included as control variables in the second stage, where the binary adoption decision is modeled (Diiro and Sam, 2015).

Parametric models can be prone to errors if their distributional assumptions are violated, potentially leading to misspecification and inaccurate estimates. These issues may result in misleading conclusions and flawed policy decisions. In contrast, semi-parametric methods for estimating binary choice models with endogenous regressors offer a more accurate and reliable alternative. For estimating causal effects involving continuous outcome variables—such as those measured in levels, quantities, or monetary terms—in observational studies, the Generalized Propensity Score (GPS) method is preferred, as it effectively adjusts for confounding bias (Xiao et al., 2018).

Christian et al. (2018) found that the semi-parametric covariate balancing propensity score method enhances robustness to model misspecification by directly optimizing covariate balance between treatment and control groups. This approach is also effective for estimating causal relationships from observational data.

Bekele et al. (2018) employed the generalized propensity score (GPS) method to assess the causal impact of Prosopis invasion on annual per capita consumption expenditure among pastoralist and agro-pastoralist households, using cross-sectional data. Their findings revealed the invasion's adverse effects on community livelihoods, offering important insights to inform policy decisions and guide appropriate interventions.

Moreno-Serra (2008) highlighted the practical applications of the GPS estimator in cases with multiple treatments. Despite data limitations in some empirical applications, the GPS approach offers significant advantages and can serve as a valuable tool for policy purposes.

Review of Food and Nutrition Security

A food system encompasses the network of processes and infrastructure required to ensure food security for a population. It includes a wide range of activities such as food collection, cultivation, harvesting, storage, processing, packaging, transportation, marketing, consumption, and waste management. Moreover, it incorporates key food security outcomes—availability, access, utilization, and stability—which are influenced by socioeconomic, environmental, and other contextual factors (Porter et al., 2014).

Food security is a complex, multifaceted condition with no precise measurement. It is typically assessed using three key components: quantity, quality, and stability of food. These components are evaluated by combining indicators such as diversity and sufficiency (Maxwell et al., 2013; Wineman, 2016).

The various dimensions of food security—short-term versus long-term and transitory versus chronic—can be measured using specific indicators. These indicators include per capita dietary calorie requirements, available food supply, and access and utilization across different districts, social classes, and households. Food insecurity can be assessed through surveys based on experience reports, actual dietary intake of all household members, household expenditures, anthropometric data, dietary intake assessments, and rapid rural appraisals. A multidimensional food insecurity index is developed using indicators from the four dimensions of food security: availability, access, utilization, and stability. These indicators are grounded in theoretical frameworks that help estimate food insecurity by combining causes and consequences and analyzing both qualitative and numerical data (Marion, 2011; FAO, 2015).

2.2. Conceptual Prospective

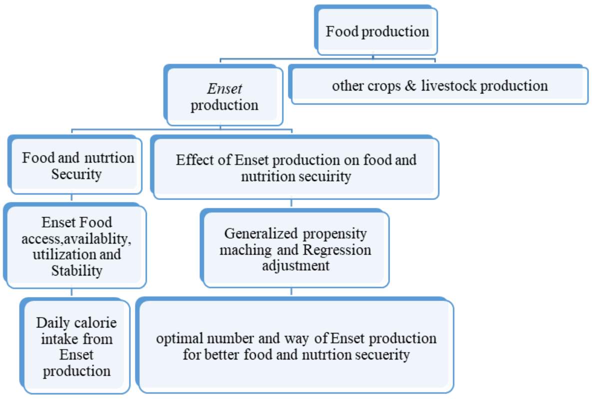

Figure 1. Conceptual Framework for Enset Production and Its Effect on Food availability, access, utilization and stability

Conceptual framework of Enset cultivation, harvesting and its causal impact on daily energy intake

As depicted in the figure 1 above, Enset production is widely regarded as being closely connected to daily energy intake. The sketched figure above points out that its level of production own causal impact on daily energy intake Enset producer households.

The production of *Enset* is hypothesised to affect the food supply of smallholder producers that, in turn, productivity, improvement and utilization of the resource. The focus of this research will be evaluating its impact on food security and identifying demographic, social, economic and institutional factors for policy direction, improvement scenario and intervention. The proposed management and improvement strategies of *Enset* resource include community based on farm biodiversity conservation, awareness creation and *Enset* nursery establishment.

2.3. Analytical Approach

2.3.1. Generalized Propensity Score

The study employed the Generalized Propensity Score (GPS) method to account for confounding variables in the context of a continuous treatment. A generalized additive model was used to examine the adjusted relationship between the treatment and the outcome, conditional on the propensity score. The main objective was to evaluate the effect of Enset production on household food security, with food security serving as the outcome variable. The treatment variable represented the level of Enset production at the household level, measured by the quantity of Enset products produced and the scale of harvesting over a specified production period.

Household food security status was assessed through a cross-sectional survey, drawing on the experiences of Enset producers. The analysis employed a multidimensional framework of food security, taking into account key components such as food availability, access, utilization, and the stability of consumption. While smallholder farmers may cultivate Enset, they might not harvest it due to factors like immaturity or access to other food sources. Households that did not harvest or utilize Enset products in the past 12 months were excluded from the regression analysis, as they were considered non-participants in Enset harvesting and consumption.

The study hypothesized and found that Enset production influenced the food supply of smallholder producers, which in turn impacted the conservation, improvement, and optimal utilization of Enset for future generations. The research focused on evaluating the causal effect of Enset cultivation and consumption on daily energy intake and identifying the demographic, social, economic, and institutional factors involved. The effects of Enset harvesting on daily energy intake was analyzed using the GPS matching method, and the optimal level of production for each study district was determined.

3. Methods

3.1. Map of Study Areas

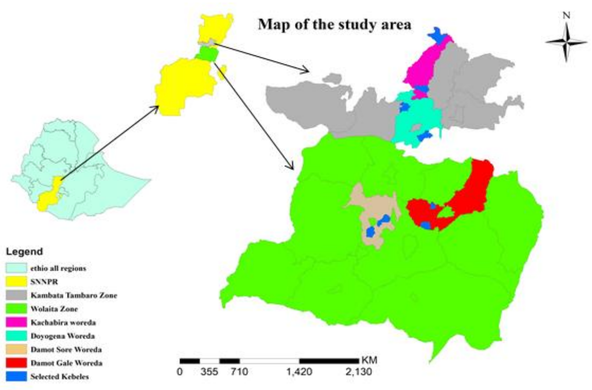

Figure 2. Map of Sampled Major Enset producer Zones and districts

3.2. Description of the Study Area

As illustrated in the figure above, the study was carried out in one of the major Enset-producing regions of South and Central Ethiopia, specifically in the Wolaita and Kembata zones. In Wolaita Zone, Enset cultivation covers a total of 7,968 hectares under indigenous seed holdings. The zone is home to 295,117 Enset-cultivating farmers. A total of 1,415,020 Enset trees were harvested, yielding 212,253 quintals of Amicho, 240,553.40 quintals of Kocho, and 14,150.20 quintals of Bulla (CSA, 2022).

3.2.1. The Study Districts of *Wolaita* Zone

Damot Gale Woreda

Damot Gale District is one of the twenty administrative districts and towns in the Wolaita Zone, with a total population of 224,356—comprising 109,402 males and 114,954 females. The district is bordered by Sodo Zuria to the southwest, Boloso Sore and Damot Pulasa to the northwest, the Hadiya Zone to the north, Duguna Fango to the east, and Damot Weyde to the southeast. According to CSA (2022), the district is home to 16,344 Enset-cultivating farmers, including 13,716 male-headed and 2,618 female-headed households.

Damot Sore Woreda

Damot Sore is an administrative district and town located in the Wolaita Zone of southeastern Ethiopia. It is bordered by Sodo Zuria to the southeast, Kindo Koiysha to the west, Boloso Bombe to the northwest, and Sore to the north. The district lies approximately 318 kilometers from Addis Ababa and is accessible via the Hosanna road. It comprises 17 rural kebeles and 3 urban kebeles, with a total population of 136,647—66,563 males and 70,084 females. Key crops grown in the area include common beans, Enset, sweet potato, maize, cassava, teff, barley, banana, and field pea. According to Areja et al. (2017) and CSA (2022), the district has 9,776 Enset-cultivating households, including 7,332 male-headed and 2,444 female-headed households.

3.2.2. The Study Districts of Kembata Zone

In the Kembata Zone, Enset cultivation spans 6,778 hectares, with 112,929 natural Enset holders. These holders have an estimated landholding of 5.805 hectares. Additionally, the zone is home to 121,558 indigenous Enset seed holders. The estimated annual Enset harvest in the zone totals 1,195,069 quintals. In the 2022 fiscal year, the production of Amicho, Kotcho, and Bulla reached 262,915.18 quintals, 298,767.25 quintals, and 11,950.69 quintals, respectively (CSA, 2022).

Kachabira Woreda

Katcha Bira Woreda, located in the Kembata zone, is one of eight administrative districts in the area. The Woreda has a total population of 165,859, consisting of 80,837 males and 85,022 females. It is divided into 21 kebeles. Within the Woreda, 9,395 households are involved in Enset cultivation, with 8,604 headed by males and 791 by females (Lelago et al., 2016).

Doyogena Woreda

Doyogena District, one of the eight administrative divisions within the Kembata Zone, has a total population of 109,251—comprising 53,379 males and 55,872 females. The district includes 14 peasant associations and is bordered by Kacha Bira to the south, Lemu Woreda in the Hadiya Zone to the west and north, and Angacha to the east. Enset cultivation plays a central role in local agriculture, with 15,660 farmers engaged—13,434 from male-headed households and 2,526 from female-headed households. Key crops grown in the area include Enset, wheat, Irish potatoes, common beans, faba beans, teff, cabbage, head cabbage, barley, field peas, beets, tomatoes, onions, carrots, and garlic (Mathewos et al., 2021).

3.3. Sampling Techniques and Sample Size Determination

Sampling Techniques

This study employed a combination of purposive (non-random) and random sampling methods. Purposive sampling was used to deliberately select the study zones, districts, and kebeles based on specific criteria, including Enset production potential, harvesting intensity, population density, and geographic characteristics. From the Wolaita Zone, Damot Gale and Damot Sore districts were selected, while Doyogena and Kacha Bira districts were chosen from the Kembata Zone due to their strong Enset production capacity. Within each district, two kebeles were purposively selected for their high production performance. Following this, an updated list of households was obtained from each kebele administration, and representative households were randomly selected for the survey.

Sample Size Determination

Following Cochran (1977) sample size determination techniques, the sample size is determined by the formula for the Kembata zone:

$$n = \frac{Z^2 * pq}{e^2} = \frac{(1.96^2)*(0.85*0.15)}{0.05^2} = 196 \quad (1)$$

Where n is the minimum number of sample untt, Z is the confidence level (t_{value})of $1.96)$;p is the estimated proportion population that could be able to sense and estimate genetic biodiversity and other related attributes of Enset, and q is $1-p$; and e is margin of error (i.e. the desired level of precision). Assuming a 95% confidence level, a 5% margin of error, and that 85% of the local population in the Kembata Zone is aware of the loss of different varieties and their economic significance (including food, biodiversity, feed, fiber, and wrapping), the estimated sample size was calculated to be 196. However, the actual survey included 199 households from the Kacha Bira and Doyogena districts in Kembata. The sample size for the Wolaita Zone was determined using the formula provided below.

$$n = \frac{Z^2 * pq}{e^2} = \frac{(1.96^2)*(0.9*0.1)}{0.05^2} = 139 \quad (2)$$

As outlined in Equation (2), the number of households surveyed in the Wolaita Zone was set at 139, while 188 households engaged in Enset harvesting were included for the impact evaluation. The sample size in the Wolaita Zone was set based on the assumption that at least 90% of the local communities in the district understood loss of different Enset varieties and the economic significance of the crop production, including its uses for food, biodiversity, feed, fiber, land rehabilitation and wrapping. This estimation considered a potentially higher level of awareness regarding biodiversity, genetic loss, and Enset-related attributes among communities in Wolaita compared to smallholder farmers in Kembata. Consequently, the planned sample size for the survey across both Wolaita and Kembata Zones was 338; however, the actual number of households surveyed was 386. Of these, the analysis focused on 374 households that produced and consumed Enset from their own harvests and market.

3.4. Data Collection Methods and Data Types

The data collection process combined key informant interviews, focus group discussions, and household surveys. Both structured and unstructured questionnaires were utilized as survey instruments. Key informant interviews were conducted with 6 experts from the two zones, 4 researchers from the Areka Agricultural Research Centre, 12 experts from four woredas, and 8 development agents from four kebeles. Focus group discussions were organized at the kebele level with Enset producers, segmented by gender and age—men, women, and youth. These sessions included 30 male and female farmers, as well as 10 youth participants.

Before finalizing the household survey questionnaire, the survey instrument was piloted in two kebeles from each of the two Woredas, involving 10 households. The survey used the quantity of Enset harvested as a reliable indicator of annual production, leveraging the perennial nature of the crop to collect cross-sectional data. The relationship between Enset consumption and the number harvested, area coverage, and consumption levels from production was also assessed.

Key data collected encompassed the extent of Enset cultivation in terms of land coverage, harvesting levels, productivity, the number of existing and lost Enset varieties, primary Enset products, market participation, livestock ownership, total landholding, and the area specifically allocated to Enset (in hectares). The study also examined gender roles across different stages of Enset production, including land preparation, variety selection, planting, weeding, harvesting, transportation, marketing, and consumption. Furthermore, the amount of time dedicated to Enset cultivation was recorded.

To estimate the daily dietary energy available per household member, food items consumed on a weekly, monthly, and annual basis were identified and converted into kilocalories. The total kilocalorie values were then aggregated, divided by the number of days in the reference period, and further adjusted by the number of adult household members to determine the per capita dietary energy availability (Napoli et al., 2011; Smith and Subandoro, 2007).

3.5 Econometric Model Specification

The GPS method, an advanced extension of propensity score matching (PSM) for multiple treatments, is implemented in three steps. In the initial step, the GPS estimate is defined as the conditional probability of a specific level of Enset harvesting, given the covariates, under the assumption of a normal distribution. Giving $r(t,x) = (fT/x\ (t/x)$ The conditional density of treatments given the covariates, GPS was defined as:

$$PS = R = r(T,X)) \tag{3}$$

Within strata with similar values of ($r(t,X)$ the probability that $T = t$ does not depends on values of X,that is GPS has the property that $X \in 1\{T = t\}/r(t,X)$.

The GPS method is applied to eliminate bias associated with differences in covariates through three stages. First, it involves modeling and defining the GPS. In the second stage, the conditional expectation of the outcome is estimated as a function of two scalar variables: the treatment and the GPS.

$$GPS\ R, \text{ i.e. } \beta(t,r) = E[Y/T = t, R = r] \tag{4}$$

For the equation, the study assumes a functional relationship between calorie intake, food and nutrition security status, the level of Enset harvesting, and the GPS. Similarly, for the second equation, the study assumes a functional form that links calorie intake, food and nutrition security status, the level of Enset harvesting, and the GPS.

The third step was to estimate the level of harvesting in production:

$$\mu(t) = E[\beta\{t, r(t,X)\}] \tag{5}$$

The procedure undertake averages over the $GPS = R = r(T,X)$ that is the score evaluated for the treatment of interest $r(t,X)$. The primary goal of estimating the GPS was to ensure the proper balancing of covariates across different levels of harvesting in production. Therefore, an assessment of the covariate balancing properties of the estimated GPS was conducted before proceeding to the next step. The other procedure used in the modelling of the conditional expectation of energy intake for food security status (Y_i) as a quadratic function of observed treatment (T_i), estimation of GPS (Ri), and analysis of the interaction between the two. Since the study used normal distribution of the level of harvesting collected, covariates

$$T_i/X_i \sim N(\beta_0 + \beta_1 X_i, \sigma^2) \tag{6}$$

This was estimated by ordinary least squares regression; here the study assured the balance of the covariates. The GPS can be estimated as:

$$R_i = \frac{1}{\sqrt{2\pi\sigma^2}}\{-\frac{1}{2\sigma^2}(T_i - \beta_0 - \beta_1 - \beta_1 X_i)^2 \quad (7)$$

In the next step, the study estimates the conditional expectation function of the probability of employment, given certain variables, as a flexible function. The experimental approach applies the following polynomial approximation:

$$E[Y_i/T_{i,}R_i] = \alpha_0 + \alpha_1 T_i + \alpha_2 {T_i}^2 + \alpha_3 {T_i}^3 + \alpha_4 R_i + \propto_n T_i {R_i}^n \quad (8)$$

The observed number of Enset harvested for production extent and the estimates for each individual were used, and the equation was estimated using OLS.

Given the estimated parameters in the in the second stage, the study estimates the average potential outcome at production level t defined as

$$E[Y(t)] = \frac{1}{N}\sum_{i=1}^{n}\{\propto_0 + \propto_1 t + \propto_2 t^2 + \propto_n tr(t, x_i)^2\} \quad (9)$$

The causal-effect function was constructed by estimating the average potential outcome at each treatment level. To address the variability arising from estimating both the Generalized Propensity Score (GPS) and the model parameters, bootstrap methods were employed—bootstrapping the entire estimation procedure. Graphical illustrations of both the causal-effect function and the marginal treatment effect function were included. The average causal-effect function highlighted the magnitude and pattern of the relationship between the level of harvesting and production, particularly in terms of its impact on energy intake. The analysis was conducted using cross-sectional survey data processed through STATA version 17, SPSS version 20, and Excel 2007 (Kluve et al., 2012).

3.6. Methods of Data Analysis

The study employed the Generalized Propensity Score (GPS) method, chosen for its effectiveness in adjusting for confounding variables in the context of continuous treatments. Here, the treatment variable was defined as the number of Enset units harvested for food, ranging from two to seventy-five units. The GPS estimation involved several key steps: modeling the conditional distribution of the treatment based on observed covariates, estimating the conditional expectation of the outcome given both the treatment and the GPS, and constructing the dose-response function (Bia and Mattei, 2008).

In the first step, efforts focused on achieving balance in the estimates, GPS values, and statistical tests while modeling the conditional distribution of the treatment. Subsequently, dose-response estimates were generated using an algorithm that included estimating the GPS, testing the normality of the GPS model, and evaluating the balancing property.

The main goal of the study was to assess the impact of Enset production on food security, using daily calorie intake as the key outcome variable. The level of Enset production among smallholder farmers was measured by the quantity harvested during a defined production period. Household food security was evaluated through a survey in which producers reported the types and amounts of food consumed over the previous seven days. Notably, some smallholder farmers may cultivate Enset without harvesting it due to the crop's immaturity. Households that had not harvested or used Enset products in the past 12 months were classified as non-participants.

4. Results and Discussions

4.1. Social, Economic and Demographic Characters of Enset Producers

Education level of Household head Farmers in Kembata Zone

The average number of years of schooling for household heads in the Doyogena and Kacha Bira districts was 4.8 years. In Doyogena, 21.9% of farmers had no formal education, 39.47% had completed up to grade six, 11.3% had completed grades six and seven, 22.1% had completed grades nine to twelve, and 5.2% had attained education beyond high school. In Kacha Bira Woreda, 21.8% of farmers had no formal education, 35.9% had completed grades one to six, 14.1% had finished grades seven and eight, and 28.2% had completed grades nine to twelve.

Education level of farmers in *Wolaita* zone

On average, farming communities in the Damot Sore and Damot Gale districts had 4.04 years of schooling. In Damot Sore, 34% of residents had no formal education, 37% had completed up to grade six, 19% had attended grades seven and eight, 3% had completed high school (grades nine to twelve), and 7% had education beyond high school. In Damot Gale, 43% of residents had no formal education, 37% had completed primary school up to grade six, 9% had attended grades seven and eight, 8% had finished high school, and 3% had attained education at the tertiary level.

Age of Kembata, Tambaro, and *Wolaita* farmers

The average age of farmers in Doyogena and Katachabira Woreda is 50 years. In contrast, the average age of farmers in the Damot Sore and Damot Gale districts is 44 years.

Table 2. Family size of the Farmers in Doyogena and Katacha Bira district (N=186)

Descriptive Statistics	Minimum	Maximum	Mean	Std. Deviation
Total family size	3.00	18.00	7.59	2.49
Family size aged bellow 5 year old	0.00	9.00	1.27	0.55
Family size aged between 5 to 14 years	0.00	7.00	1.65	.34
Family size aged between 15 to 65 yeas	0.00	11.00	4.21	1.24
Family size above 65 year old	0.00	6.00	.61	0.15

As indicated in the table above, 55.47% of smallholder farmers belong to the active labour force, whereas 44.53% fall into the dependent age group. The result also showed that the small holder farmers around Kembata zone lives long life than that of Wolaita zone communities.

Table 3. Education level of farmers in *Wolaita* Zone

Descriptive Statistics	Minimum	Maximum	Mean	Std. Deviation
Total family size	2.00	12.00	6.41	2.18
Family size aged bellow 5 year old	0.00	12.00	0.91	0.32
Family size aged between 5 to 14 year	0.00	5.00	1.46	0.13
Family size aged between 15 to 65 years old	0.00	11.00	4.04	1.96
Family size above 65 year old	0.00	7.00	0.23	0.15

As indicated in the table above, 63% of smallholder farmers are part of the active labor force, while 37% of households are classified as dependents.

3.2. Enset Consumption Occasions, Sources and Free Provision Feature of Producers Between Zones

Table 4. Chi squared analysis result of consumption occasions between zones

zone	Consume occasionally	Consume Enset for whole year	Total	Two sample test of proportion for occasional consumption		
Wolaita zone (N)	165	13	178		Wolaita Sample	Kembata Sample
Row percent	92.70	7.30	100.00	Size	165	65
Column percent	71.74	9.03	47.59	Proportion	0.7172	0.2826
Kembata Zone (N)	65	131	196	Z	6.05	

Row percent	33.16	66.84	100.00	Two sample test of proportion for whole year consumption		
Column percent	28.26	90.97	52.41		Wolaita Sample	Kembata Sample
Total (N)	230	144	374	Size	13	131
Total Percent	61.50	38.50	100.00	Proportion	0.0903	0.9097
Total percentage	100.00	100.00	100.00	Z	-7.61	
Pearson chi2(1)	= 139.63	Pr = 0.000				

The Chi-Squared Analysis results for categorical variables in Table 4 above show a significant difference in Enset consumption across zones for various occasions (festivals, holidays, and lean periods) as well as for year-round consumption, based on different socioeconomic, demographic, and institutional characteristics of smallholders. The two-way test of proportions within the Wolaita and Kembata zones revealed significant differences in the consumption patterns of Enset on both occasional and year-round bases. Additionally, the results suggest that Enset consumption in the Wolaita zone is more inclined toward occasional consumption, while in the Kembata zone, it tends to be focused on year-round consumption.

Table 5. Enset products source of consumption between zones

Zones	Enset used from own production and market	Enset used from own production	Total	Two-sample test of proportions for market & own production source		
Wolaita	79	99	178		Wolaita	Kembata
Row %	44.38	55.62	100.00	Size	79	40
Column %	66.39	38.82	47.59	Proportion	0.6639	0.3882
Kembata	40	156	196	Z	3.39	
Row %	20.41	79.59	100.00	Two-sample test of proportions for own production source		
Column %	33.61	61.18	52.41		Wolaita	Kembata
Total (N)	119	255	374	Size	99	156
Percent	31.82	68.18	100.00	Proportion	0.3882	0.6118
Percent	100.00	100.00	100.00	z	-3.49	
Pearson chi2(1) = 24.7136	Pr = 0.000	Cramér's V =	0.2571			

The results in Table 5 above indicated that there is a significant difference between zones in the sources of Enset for consumption. Specifically, Enset producers in the Wolaita zone rely on both market sources and their own production, while farmers in the Kembata zone primarily consume Enset from their own production. Additionally, the findings suggest a significant difference within the Kembata zone regarding the use of Enset from the market versus only from their own production.

Table 6. Enset free provision between Wolaita and Kembata zones

Study zones	No free provision	Gives Enset for free	Total	Two-sample test of proportions for no free provision		
Wolaita zone	142	36	178	Size	Wolaita	Kembata
Row %	79.78	20.22	100.00	Size	142	51
Column %	73.58	19.89	47.59	Proportion	0.7358	0.2642
Kembata (N)	51	145	196	Z	5.93	
Row %	26.02	73.98	100.00	Two-sample test of proportions for free provision of Enset products		
Column %	26.42	80.11	52.41	Size	Wolaita	Kembata
Total (N)	193	181	374	Size	36	145
Total %	51.60	48.40	100.00	Proportion	0.1989	0.8011
	100.00	100.00	100.00	Z	-6.94	
Pearson chi2(1) = 107.93		Pr = 0.00	Cramér's V = 0.54			

The chi-squared analysis results in Table 6 above indicate a significant difference between zones regarding the free provision of Enset products. The provision of various Enset products was more prevalent in the Kembata zone compared to the Wolaita zone. These free Enset products, such as Kotcho, seedlings, and fiber, play a crucial role in fostering social ties and community relationships.

4.3. Impact of Enset Production on Food and Nutrition Security

Table 7. Common support region

Variable	Dosage of Enset	Treatment proportion	Obs	Mean	Std. dev.	Min	Max
gps_1	<=8	27.81%	374	0.14	0.10	0.00001	0.62
Variable			Obs	Mean	Std. dev.	Min	Max
gps_2	> 8 & <=14	24.33%	374	0.43	0.16	0.002	0.74
Variable			Obs	Mean	Std. dev.	Min	Max
gps_3	>14 & <=24	25.40%	374	0.52	0.20	0.02	0.73
Variable			Obs	Mean	Std. dev.	Min	Max
gps_4	>24	22.46%	374	0.38	0.25	0.02	0.74

The study revealed that 27.81% of smallholder farmers harvest between two and eight Enset plants per year, while 24.33% harvest between nine and fourteen. Furthermore, 25.40% harvest between fifteen and twenty-four plants, and 22.46% harvest more than twenty-four Enset plants annually for consumption. The common support region, determined by the minimum and maximum estimated propensity scores, ranges from 0.02 to 0.62. This means households with scores outside this range—below 0.02 or above 0.62—were excluded from the matching process.

Estimation of Generalized Propensity Score

The Generalized Propensity Score (GPS) was estimated using the number of Enset plants harvested as a continuous dependent variable, including only positive values. Households were categorized as participants or non-participants in Enset production based on whether they harvested Enset from their own farms and the quantity harvested. Households that did not harvest Enset from their own farm plots were excluded from the analysis.

In the initial step of estimating the GPS, participants were divided into four groups using the 30th and 70th percentiles as cut-off points (Kluve et al., 2012). These four groups, roughly equal in size, were defined by the number of Enset plants harvested: Group one (2–8 plants), Group two (9–14 plants), Group three (15–24 plants), and Group four (more than 24 plants). Group one, representing the lowest level of Enset harvesting, included the highest proportion of smallholder farmers (27.81%), while Group four, which reflected higher levels of Enset harvesting, accounted for a smaller share (22.46%). Groups two and three comprised 24.33% and 25.40% of the smallholders, respectively.

Table 8. Estimate of Generalized Propensity Score

T	Coefficient	Std. err.	z	P>z	[95% conf. interval]	
eq.1 TLU***	0.0947971	0.0292125	3.25	0.001	0.0375416	0.1520525
Total land owned	0.021382	0.0175439	1.22	0.223	-0.0130033	0.0557674
Enset source***	0.4019197	0.0647063	6.21	0.000	0.2750978	0.5287417
Total family size***	0.0399083	0.0124855	3.20	0.001	0.0154372	0.0643795
Education level*	0.0006586	0.0078335	0.08	0.933	-0.0146948	0.016012
Age*	0.0001803	0.0022679	0.08	0.937	-0.0042647	0.0046254
Zone***	0.3763774	0.0700494	5.37	0.000	0.2390831	0.5136717
Transplanted Enset***	0.0003464	0.0000629	5.51	0.000	0.0002231	0.0004697
Market distance	0.0011697	0.0006716	1.74	0.082	-0.0001466	0.0024861
FTC distance	-0.0011733	0.001057	-1.11	0.267	-0.0032449	0.0008983
EBW avail*	0.0954599	0.0577768	1.65	0.098	-0.0177806	0.2087004
_cons	-0.6333453	0.1616775	-3.92	0.000	-0.9502274	-0.3164632
eq.2 cons	0.5363107	0.0196095	27.35	0.000	0.4978769	0.5747446
Number of observation 374				Log	likelihood	-297.67
Wald	chi2(11)	=	360.33	Prob	> chi2	=0.000

***** and * denote Significance at 1% and 10%, respectively.**

In the first step, the Maximum Likelihood (ML) estimator was employed to estimate the conditional distribution of Enset harvesting levels based on a range of demographic, institutional, and socioeconomic variables. The covariates used in calculating the Generalized Propensity Score (GPS) included tropical livestock units, land size, number of matured Enset plants, source of Enset harvested, education level, age category, presence of Enset Bacterial Wilting (EBW) on the farm, and family size. The normality assumption was statistically satisfied at the 0.01 significance level. It's important to emphasize that the primary objective of GPS estimation was not to interpret individual coefficients, but rather to achieve covariate balance. The results of the balancing test confirmed that the GPS effectively met the required balancing criteria.

Table 9. Results of the dose-response function of Enset production for daily energy intake

Source	SS	df	MS	Number of obs =366	
				F(4, 361) =4.00	
Model	152214948	4	38053737	Prob > F	=0.0034
Residual	3.4302e+09	361	9501909.94	R-squared	=0.043
				Adj R-squared =0.032	
Total	3.5824e+09	365	9814806.68	Root MSE	=3082.5

Total_kcal intake	Coefficient	Std. err.	T	P>t	[95% conf. interval]	
Enset harvest	-573.16**	223.17	-2.57	0.011	-1012.04	-134.27
Gps	-20620.57***	6195.39	-3.33	0.001	-32804.17	-8436.97
gps_sq	21306.5**	8332.68	2.56	0.01	4919.79	37693.2
Enset harvest-gps	2461.30***	943.65	2.61	0.009	605.57	4317.04
_cons	7509.16	1021.92	7.35	0.000	5499.49	9518.83

The statistical significance indicated * for 99% and ** for 95% significance.**

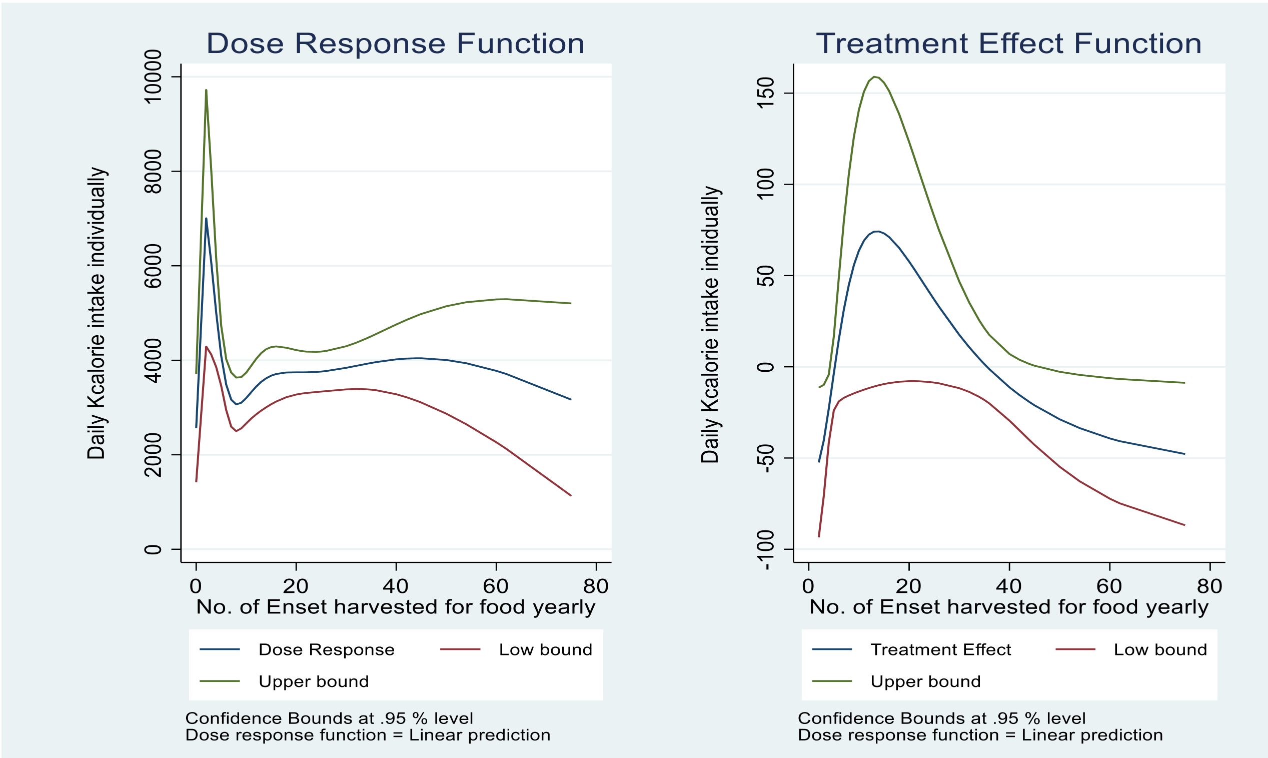

Figure 3 Dose response and treatment effect function

Impact of Level of Enset Harvesting on Food and Nutrition Security

Figure 2 above shows estimates of the Dose-Response Function (DRF) for the causal effect of Enset harvested for food on household total energy intake in calories. The relationship is non-linear and negatively correlated, indicating that energy intake decreases as the number of Enset harvested for food increases. Energy intake rises up to the point of thirteen Enset units, after which the overall trend shows a decrease in energy intake as more Enset is harvested for food. A noticeable increase in energy intake occurs up to the level of thirteen Enset. The overall inverse relationship between the number of Enset harvested and daily energy intake suggests that Enset producers, with improved food and nutrition security, require supplementary foods such as dairy products and pulses for a balanced diet. This finding aligns with Meaza (2021) and Jacobsen et al. (2018), who reported that an Enset-based diet needs supplementation with nutrient-rich foods to improve nutrition and dietary diversity.

At lower levels of Enset harvesting, the correlation between the quantity of Enset and energy intake is direct and positive, suggesting a significant causal effect on household energy intake at optimal levels of production. However, beyond this optimal point, total household energy intake decreases as the quantity of Enset harvested increases. The marginal effect functions reflect this trend, reinforcing the observations of the dose-response function. Thus, the noticeable impact on farmers' total energy intake occurs when Enset harvesting reaches thirteen units.

These findings emphasize the positive association between lower levels of Enset production and higher energy intake, while a more inverse relationship exists with higher quantities of Enset harvested. At lower levels of harvesting, Enset production seems to have a positive causal effect on household energy intake, which becomes negative at higher levels of harvesting. The regression results confirm the negative relationship between Enset production below two units and above four units. The optimal level for Enset harvesting, conducive to food and nutrition security, is found to be thirteen units, with an associated yearly household energy intake of 5592.77 kilocalories. These findings support Morrow et al.'s (2023) conclusions, suggesting that the level of Enset harvested can significantly enhance estimates of food security indicators, serving as a safeguard and proactive adaptation strategy in the face of adversity.

Enset Source for Consumption and Food and Nutrition Security

Table 10. Treatment-effects estimation by regression adjustment

total_kcal_for1daysper~1	*Robust Coefficient*	*std. err.*	*z*	*P>z*	*[95% conf. interval]*	
ATE of Enset source (own production versus market)	-806.84	377.53	-2.14	0.03	-1546.79	-66.89
P*otential* Outc*ome* mean *of* Enset sour*ce from market*	4420.96	345.37	12.80	0.00	3744.06	5097.86
Estimator : regression adjustment		Number	of	Obs	=	374
Outcome model : linear		Treatment model: none				

As shown in Table 10 above, we used regression adjustment to estimate the average treatment effect. The model for the outcome variable, calorie intake, was defined as a function of socioeconomic, demographic, and institutional variables, with the source of Enset as the treatment variable. The source of Enset was defined as either own production only or a combination of own production and market sources. Smallholder farmers typically use Enset from both their own production and market sources for food. The outcome variable is the total kilocalorie energy intake, while the independent variables include zone, current Enset area, age, education level, market distance, family size, land owned, tropical livestock units, and the number of matured Enset plants.

If all smallholder farmers were to obtain Enset for food solely from their own production, their average daily energy intake would be 806 kilocalories less than the average of 4,420 kilocalories that would occur if they obtained Enset from both their own production and market sources. The estimated average daily kilocalorie intake for smallholder farmers obtaining Enset from both sources is 4,420 kilocalories. The regression results above imply that enabling all smallholder farmers to consume Enset from various sources, such as own production and the market, would improve their average daily energy intake. The results also indicate that the average daily energy intake of individuals in households is influenced by their ability to access additional Enset sources, such as the market. Therefore, increasing the level and availability of Enset production contributes to the food and nutrition security of Enset producers.

Quantities of Enset harvested versus food and nutrition security

Table 11. Treatment-effects estimation by regression adjustment

Total_kcal_for1daysper	Robust Coefficient	Std. err.	Z	P>z	[95% conf. interval]	
ATE of various level of Enset harvested for food						
Medium versus lower level (2 vs 1)	-130.67	36.52	-0.43	0.67	-731.43	470.10
Higher versus lower level (3 vs 1)	602.99	348.08	1.73	0.08	-79.24	1285.21

Potential outcome mean for lower level						
lower level of Enset harvested (1)	3578.26	231.75	15.44	0.00	3124.04	4032.48
Estimator : regression adjustment		Number of observation = 374				
Outcome model	: linear	Treatment model			: none	

The number of Enset harvested annually for food varied across households depending on the socioeconomic, institutional, and demographic characteristics of the Enset producers. The different levels of Enset harvested for food were categorized as higher, medium, and lower, corresponding to more than 24 Enset plants, 14 to 24 Enset plants, and 13 or fewer Enset plants harvested and processed for food, respectively. The average total energy intake for households with a higher level of Enset harvesters was 603 kilocalories more than the average of 3,578 kilocalories for households that harvested a lower level of Enset for food.

The results in Table 11 above indicated that a higher level of Enset harvesting led to an increase in daily energy intake; however, the causal effect was not proportional. The findings also revealed that a higher level of Enset harvesting could not assure the optimal level of production and does not result in a proportional increase in household energy intake. The results suggest that a lower level of Enset production is the optimal level and is sufficient to ensure food and nutrition security for Enset producers.

5. Conclusions and Policy Implications

The aim of the study was to examine the causal effect of the annual quantity of Enset harvested on the food availability, access, utilization and stability of rural households. Specifically, it sought to estimate the causal exposure function of Enset production for household consumption and its influence on daily caloric intake. This analysis is particularly relevant in the context of subsistence farming, where ensuring food availability, access, utilization and access is critical—especially in the densely populated areas of Southern Ethiopia. In these regions, Enset cultivation plays a vital role in the dietary systems of smallholder farmers, particularly in the Wolaita and Kembata zones.

Through a cross-sectional survey of sampled Enset producers, the study aimed to provide information crucial for policy formulation and effective intervention strategies to ensure sustainable food and nutrition security. The Generalized Propensity Score (GPS) technique was chosen due to its advantages over standard binary treatment propensity score matching techniques, as well as its suitability for analyzing the full dose-response function. The treatment effect of different levels of Enset production and sources was analyzed using regression adjustment.

Enset was selected for analysis because of its importance as a staple crop in Southern and Central Ethiopia, providing a low-cost and sustainable means of meeting households' carbohydrate needs. The study results indicate that lower and optimal levels of Enset production positively affect individuals' energy intake, thereby improving food and nutrition security. The relationship between the number of Enset harvested and energy intake was found to be nonlinear and indirect, meaning changes in Enset harvested do not necessarily lead to proportional changes in carbohydrate intake. This suggests that not all of the Enset harvested is used for food, as some is allocated to other household cash demands, shifting cultivation practices, changes in farming systems, and greater priority given to cash crops, annual crops, and short-duration crops. The results also indicate that providing Enset producers with additional sources of Enset for food contributes to an increase in daily energy intake.

The study found that food availability, access, utilization and stability increases at an accelerating rate within the lower treatment category—specifically, for households harvesting 13 or fewer Enset units harvested annually. The highest recorded daily energy intake was 4,800 kilocalories among those harvesting 75 units, while the lowest was 3,900 kilocalories among those harvesting only two units. These findings indicate that greater Enset harvest volumes do not necessarily translate into improved food and nutrition security. The relatively low energy intake observed in the study areas may be due to farmers not consuming Enset products directly for food, instead diverting them to meet other household financial needs.

In regions like Ethiopia, where governments aim to ensure household food security, enabling smallholder farmers to integrate Enset production with other food crop systems and diversify their food and income sources through improved production and technology dissemination systems offers a cost-effective and efficient strategy. Overall, these findings provide valuable insights for rural communities engaged in Enset cultivation, offering a clear direction for improving household daily calorie intake.

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