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Enset Cultivation and Its Effects on Household Food Security and Economic Well-Being in Hadiya Zone Central Ethiopia

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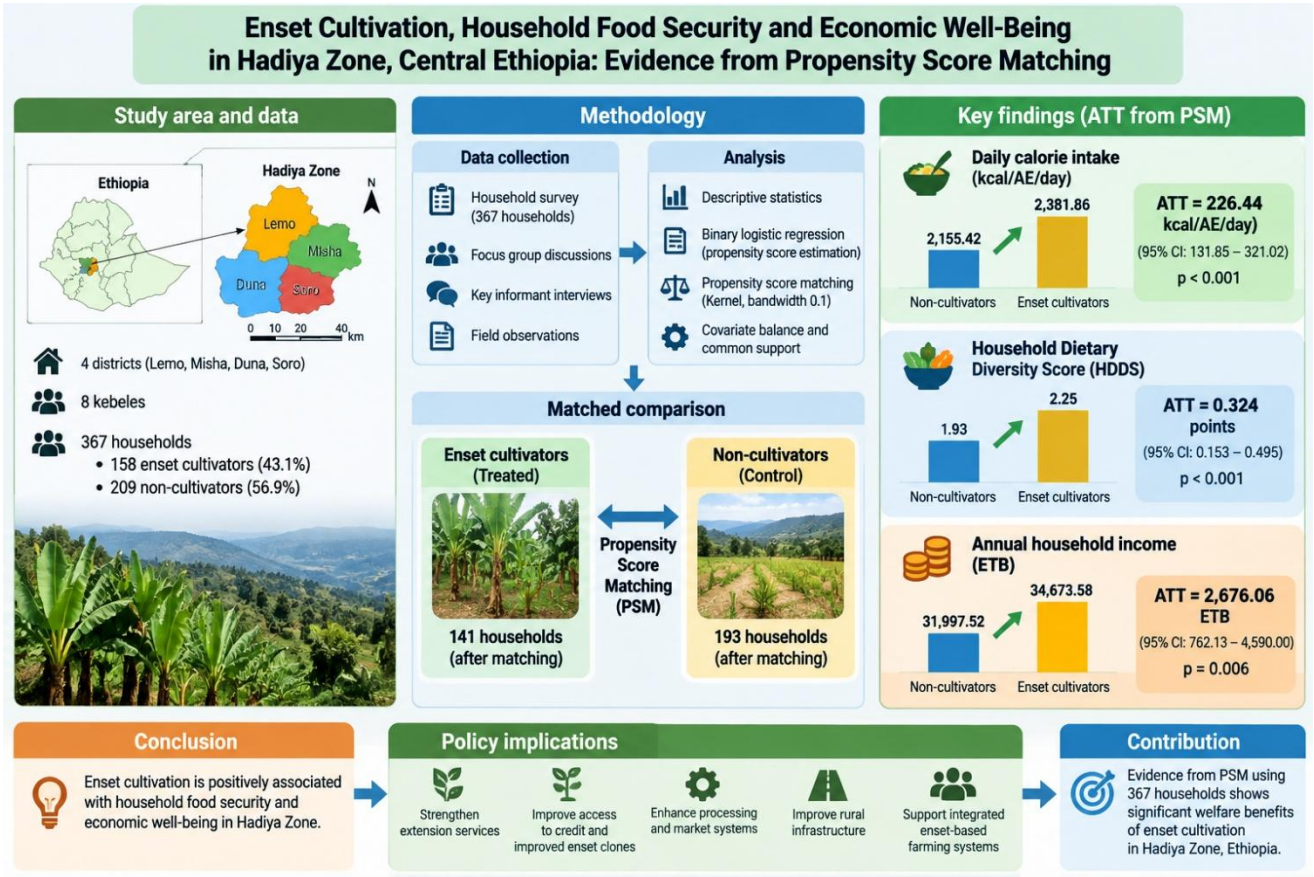
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Abstract

Enset (Ensete ventricosum) is an important food and livelihood crop in Ethiopia. However, househo ld-level evidence on its association with multiple dimensions of food security and economic well-being remains context-specific. This study examined the association between enset cultivation and household daily calorie intake, dietary diversity, and annual household income in Hadiya Zone, Central Ethiopia. A cross-sectional mixed-methods design was used, with a multistage household survey covering 367 households, including 158 enset cultivators and 209 non-cultivators. Descriptive statistics and a propensity score matching (PSM) framework were employed. A propensity score model was used to estimate the probability of enset cultivation from observed pre-treatment household characteristics, followed by a common-support restriction, a covariate-balance assessment, and estimation of the average treatment effect on the treated (ATT). Descriptively, enset cultivators reported higher mean daily energy availability (2,531.95 kcal/AE/day) than non-cultivators (1,903.74 kcal/AE/day), a difference of 628.21 kcal/AE/day. Cultivators also had a higher mean HDDS (2.40 versus 1.58) and higher mean annual household income (36,065.51 versus 31,038.18 ETB). Kernel matching with a bandwidth of 0.1 retained 141 treated and 193 comparison households after 26 observations were discarded outside common support. The manuscript's numerical ATT estimates for calorie intake, HDDS, and income are not contained in the current document and must be inserted from the original statistical output before submission. The findings indicate substantial descriptive differences between enset cultivators and non-cultivators, while causal interpretation depends on the final PSM estimates and the identifying assumptions of conditional independence and common support.

Keywords: Enset cultivation; household food security; dietary diversity; household income; propensity score matching; Hadiya Zone; Ethiopia

Graphical Abstract



1. INTRODUCTION

Food insecurity remains a major development challenge in Ethiopia, particularly among smallholder farming households whose food access and livelihoods are highly dependent on agricultural production. Rapid population growth, shrinking landholdings, climate variability, land degradation, and limited access to agricultural inputs and markets continue to constrain rural households' ability to secure adequate and diverse food supplies. These challenges have heightened interest in crops and farming systems that can simultaneously support food availability, household income, and resilience under changing environmental and socioeconomic conditions. In this context, enset (Ensete ventricosum (Welw.) Cheesman), an indigenous perennial crop domesticated and cultivated in Ethiopia, has attracted increasing attention for its distinctive role in food systems and smallholder livelihoods (Peveri, 2021; Borrell et al., 2020).

Enset is cultivated extensively across parts of central, southern, southwestern, and Oromia regions of Ethiopia, supporting the livelihoods and food systems of more than 20 million people (Sahle et al., 2021). Its perennial growth habit, tolerance to periodic drought, high productivity per unit of land, and ability to remain standing in the field for extended periods distinguish it from many annual food crops and may provide households with an important buffer against climatic and production shocks (Morrow et al., 2023). Enset is also culturally embedded in the farming systems of many communities and contributes to household food supply through products such as *kocho*, *bulla*, and *amicho*. Nutritionally, enset-based foods are predominantly sources of carbohydrates and can contribute substantially to household energy intake, although they are relatively limited in protein and fat (Yemata, 2020; Mohammed et al., 2013; Bosha et al., 2016). These characteristics have led to growing recognition of enset as an important component of food-security strategies in densely populated agricultural areas.

Beyond direct food provision, enset may support household livelihoods through income generation, consumption smoothing, crop diversification, and the provision of agricultural residues and other multipurpose resources. Enset-derived products can be marketed, while the crop can remain integrated with livestock and other crop enterprises within smallholder farming systems (Kudama et al., 2022a; Mulatu, 2021). Its potential contribution to climate resilience and sustainable agricultural production has therefore attracted increasing research attention (Borrell et al., 2020; Chase et al., 2023). However, these potential benefits do not necessarily imply that enset cultivation uniformly improves household food security. The magnitude and direction of the relationship may depend on household resources, the scale and intensity of production, land availability, access to markets and extension services, livelihood strategies, agroecological conditions, and how households allocate enset production between consumption and income-generating activities.

Recent empirical research has begun to move beyond descriptive assessments of the importance of enset toward estimating its relationship with household food-security outcomes. For example, Bassa et al. (2024) examined the effect of the level of enset production on food and nutrition security using data from 374 households in Wolaita and Kembata Tembaro Zones of Southern Ethiopia. Rather than treating enset simply as a production characteristic, the study used a Generalised Propensity Score (GPS) approach to estimate the relationship between harvested enset and household energy intake. Their findings indicate that the level of enset harvested was associated with differences in daily energy intake, while the relationship was nonlinear, suggesting that increases in enset production do not

necessarily translate proportionally into improvements in food and nutrition security. Importantly, this evidence demonstrates that the relationship between enset production and food-security outcomes requires empirical assessment rather than assuming a uniform positive effect (Bassa et al., 2024).

Nevertheless, important questions remain unresolved. First, Bassa et al. (2024) focused on the level or quantity of enset harvested and primarily examined household energy intake as the food-security outcome. This leaves uncertainty about whether households that cultivate enset as a farming practice, compared with otherwise comparable non-cultivating households, experience broader improvements across multiple dimensions of food security and household economic well-being. Second, evidence from Wolaita and Kembata Tembaro cannot automatically be generalized to other enset-producing areas because farming systems, land resources, market conditions, institutional support, demographic characteristics, and agro-ecological environments vary considerably across Ethiopia. Third, although previous studies have documented the nutritional and economic importance of enset, relatively limited empirical evidence simultaneously examines multiple household-level outcomes while explicitly accounting for observable differences between enset cultivators and non-cultivators.

This gap is particularly relevant in Hadiya Zone of Central Ethiopia, where enset is deeply integrated into smallholder farming and household food systems. Despite the importance of enset in the area, empirical evidence remains limited concerning whether participation in enset cultivation is associated with measurable differences in household food security and economic well-being after accounting for differences in household characteristics. In particular, limited attention has been given to the combined outcomes of daily calorie intake, household dietary diversity, and household income**.** Understanding these relationships is important because enset may influence food security through several pathways: direct household consumption, income obtained from the sale of enset products, substitution for purchased food, and its integration with other crop and livestock activities. At the same time, households that cultivate enset may differ systematically from non-cultivating households in education, landholding, labour availability, and access to extension services, credit, market opportunities, and other characteristics that can themselves influence food-security outcomes.

Consequently, a simple comparison between enset-producing and non-producing households may produce biased estimates if these observable differences are not adequately considered. This study therefore adopts a counterfactual perspective and uses Propensity Score Matching (PSM) to estimate the association between enset cultivation and selected household food-security and economic outcomes while reducing observable selection differences between cultivators and non-cultivators.

The analysis specifically examines whether enset cultivation is associated with differences in daily calorie intake, household dietary diversity, and household income, and evaluates the magnitude of these differences after matching households with similar observed characteristics.

The study addresses a specific empirical gap in the enset literature by shifting the focus from the general potential benefits of enset toward the measurable household-level outcomes associated with participation in enset cultivation in Hadiya Zone. In doing so, it complements rather than duplicates the work of Bassa et al. (2024): whereas their analysis examined the dose-response relationship between the quantity of enset harvested and household energy intake using GPS in Wolaita and Kembata Tembaro, the present study compares enset cultivators and non-cultivators and considers multiple indicators of food security and economic well-being within the Hadiya context. This contextual and outcome-based distinction provides additional evidence on whether the role of enset extends beyond calorie provision to broader dimensions of household welfare.

Accordingly, the objective of this study is to estimate the association/treatment effect of enset cultivation with household food security and economic well-being in Hadiya Zone, Central Ethiopia, with particular emphasis on daily calorie intake, household dietary diversity, and annual household income. Because the study uses observational cross-sectional data, causal interpretation is conditional on the validity of the PSM identifying assumptions.

2. MATERIALS AND METHODS

2.1. Description of the study area

According to the simplified agro-climatic classification of Ethiopia, the Hadiya Zone spans three distinct agro-climatic zones, covering a total area of 363,560.5 hectares. These zones include the temperate and cold highlands, locally referred to as Dega or Hansawa (ranging from 2500-3200 meters above sea level), the warm midlands, known as Woinadega or Hansaw kaala (ranging from 1500 to 2500 meters above sea level), and the hot and arid lowlands, also called Kola or Qaala (ranging from 500 to 1500 meters above sea level). Each of these zones constitutes 23.7%, 64.7%, and 11.6% of the land area, respectively (Nurebo, 2017). The research conducted by Adimassu, Z. et al. (2023) further categorizes the sampled districts, designating Misha, Duna and Lemo, Soro as dega and woina dega, respectively. As indicated in Fig. 1, the zone is located between the latitudes of 7^0 07'- 7^0 92' N and 37^0 29'- 38^0 13'E longitude (HZFED, 2022).

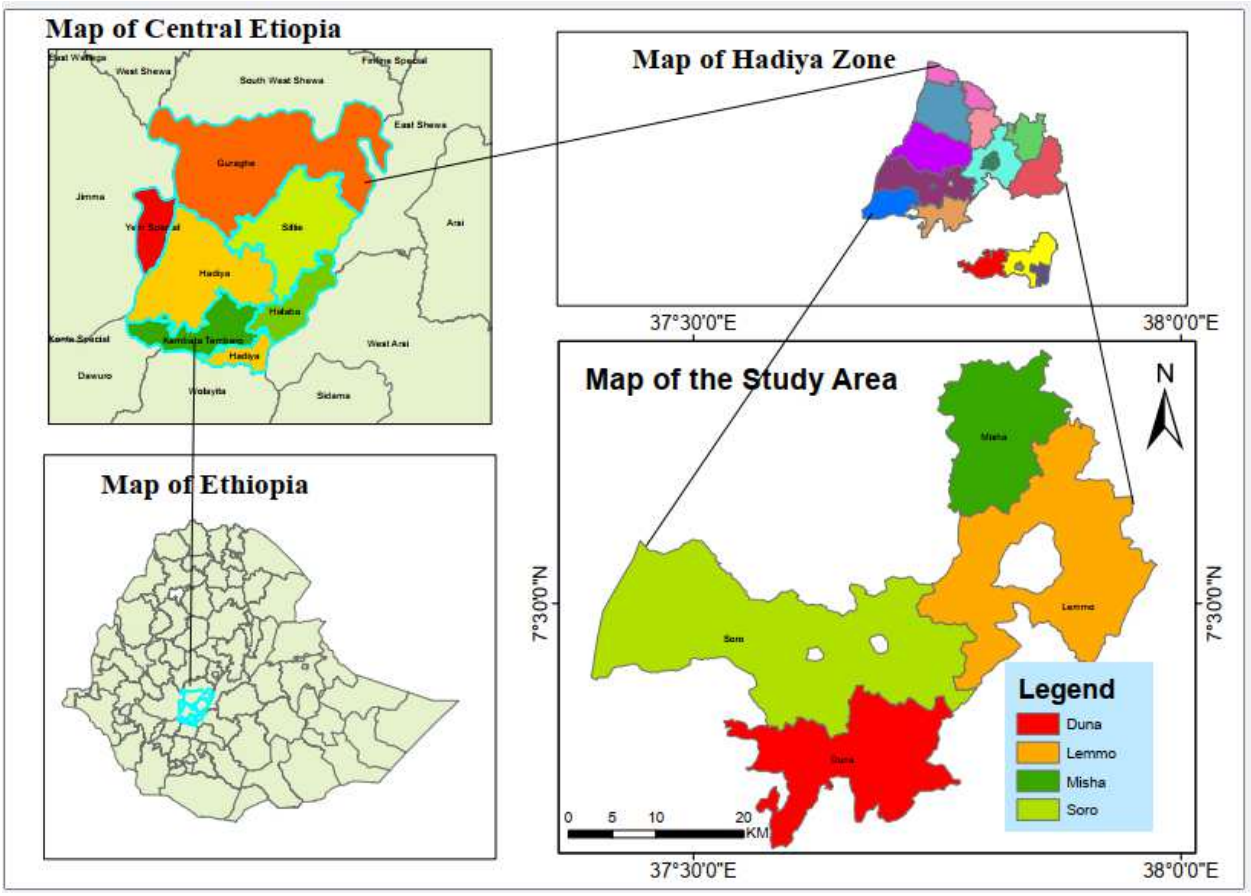


Figure 1. Map of the study area

2.2. Research Design and Approach

This study employed a **cross-sectional mixed-methods research design**, integrating quantitative household survey data with qualitative information to examine the relationship between enset cultivation and household food security and economic well-being. Quantitative data were collected from enset-cultivating and non-cultivating households using a semi-structured questionnaire, while qualitative information obtained through open-ended questions and complementary discussions was used to provide contextual understanding of household production practices, food-security conditions, and constraints affecting enset cultivation.

The quantitative component constituted the principal analytical component of the study. Descriptive statistics were first used to characterize the sampled households and compare enset cultivators and non-cultivators. Econometric techniques were then employed to identify factors associated with enset cultivation and to estimate differences in household outcomes between cultivators and comparable non-cultivators. In particular, a binary logistic regression model was used to examine determinants of

enset cultivation**,** while Propensity Score Matching (PSM) was employed to estimate the effect of enset cultivation on household food security and economic outcomes.

This analytical structure distinguishes the factors associated with households' decisions to cultivate enset from the subsequent estimation of the outcomes associated with cultivation, thereby reducing conceptual overlap between the two econometric approaches.

2.2.1. Sampling Procedure

The study was conducted in Hadiya Zone of Central Ethiopia. A multistage sampling procedure was employed to select woredas, kebeles, and household respondents. In the first stage, four woredas, Lemo, Misha, Duna, and Soro, were randomly selected from the eleven enset-producing woredas of Hadiya Zone. In the second stage, eight enset-producing kebeles, with two kebeles selected from each woreda, were selected using a simple random sampling procedure.

In the third stage, households were selected using a proportionate probability sampling procedure based on the household population of the selected kebeles. Both enset-cultivating and non-cultivating households were included to establish treatment and comparison groups for the subsequent analysis. The final sample comprised 367 households. The inclusion of both cultivating and non-cultivating households was essential for the counterfactual analysis because PSM requires a treatment group consisting of households cultivating enset and a comparison group consisting of households that did not cultivate enset but had comparable observable characteristics.

2.3 Sample Size Determination

The sample size was determined using Kothari's (2004) finite-population sample-size formula:

$$n = \frac{Z^2 pq\, N}{e^2(N-1) + Z^2 pq} \quad n = \frac{(1.96)^2(0.5)(0.5)\ 9280}{(0.05)^2(9280-1) + (1.96)^2(0.5)(0.5)} = 366.469 \text{ ---------- (1)}$$

$$\approx 367$$

Where: n is the sample size from a finite population, N is the total size of the household population, Z is the confidence level (α = 0.05), p is the sample proportion of successes (frequency estimated for a sample of size n), where p is 0.5, which is taken for all developing countries, q = 1- p, and e is the acceptable margin of error.

Using N = 9280, Z = 1.96, p = 0.5, q = 0.5, e = 0.05, the calculated sample size was approximately **367 households**. The final sample therefore consisted of 367 households.

The sample was subsequently allocated among the selected kebeles using proportionate probability sampling: $ni = \frac{Ni(n)}{\sum Ni}$ ---------- (2)

Where n_i is the sample size allocated to the i^{th} PA's, N_i is the household population of the i^{th} PAs; $\sum Ni$ is the total household population of all selected kebeles, and n is the total sample size.

2.4 Data Sources and Data Collection

The study relied primarily on primary household-level data, supplemented by secondary information. Primary data were collected using a semi-structured questionnaire containing closed- and open-ended questions. The questionnaire captured information on household demographic and socioeconomic characteristics, enset cultivation and production, landholding, food consumption, dietary diversity, household income, access to extension services and credit, market access, agricultural experience, and production constraints.

Secondary information was obtained from relevant academic publications, government reports, institutional documents, and official sources, including the Ministry of Agriculture (MoA), Ethiopian Institute of Agricultural Research (EIAR), Central Statistical Agency (CSA), and other relevant institutions.

2.5 Measurement of Household Food Security and Outcome Variables

Because household food security is multidimensional, the study considered three principal outcome measures: daily calorie intake, household dietary diversity (HDDS), and annual household income. These outcomes were analyzed separately because they represent different dimensions of household welfare and food security.

2.5.1 Daily Calorie Intake

Daily calorie intake was measured from household food consumption reported for the specified recall period and converted into kilocalories per adult equivalent per day. The total quantity of food consumed was converted into energy using appropriate food-composition information, and household consumption was standardized by adult-equivalent units.

The resulting measure represents the household's daily energy availability per adult equivalent and was used as a continuous food-security outcome in the PSM analysis.

2.5.2 Household Dietary Diversity Score

Household dietary diversity was measured using the Household Dietary Diversity Score (HDDS), based on the number of distinct food groups consumed by the household during the previous 24 hours. A higher HDDS indicates consumption from a greater variety of food groups and therefore represents a broader dimension of household dietary quality and diversity. HDDS was analyzed as a separate outcome from daily calorie intake because calorie availability and dietary diversity capture different dimensions of household food security.

2.5.3 Household Income

Household income was measured as the annual net household income reported for the 2024 production/income year. Income included relevant sources of agricultural and non-agricultural earnings after accounting for applicable production costs. Household income was treated as a continuous measure of economic well-being.

2.5.4 Measurement of Household Food Security Status

Household food-security status was also reported as a binary descriptive outcome (food secure versus food insecure). However, the current manuscript does not provide sufficiently explicit thresholds or an algorithm for reproducing the reported composite classification. Therefore, the binary status should not be presented as a principal causal PSM outcome until the exact classification rule is documented.

Daily calorie intake captures household energy availability per adult equivalent; HDDS captures the variety of food groups consumed during the reference period; and annual household income captures economic well-being and purchasing capacity. The manuscript reports a binary food-security classification, but the exact operational rule used to combine the component indicators needs to be stated explicitly in the final version. The reported descriptive totals are addressed in the Results section.

The binary variable was coded as: $FS_i = \begin{cases} 1, \text{if household i is food secure} \\ 0, \text{if household i is food insecure} \end{cases}$

Daily calorie intake, HDDS, and annual household income were retained as separate outcomes in the PSM analysis because each captures a distinct dimension of household food security or economic well-being.

2.6 Definition of Treatment and Comparison Groups

The principal treatment variable in the PSM analysis was **enset cultivation**. Households were classified into two groups:

$D_i = 1$, if household i cultivates enset;
$D_i = 0$, if household i does not cultivate enset.

Thus, enset-cultivating households constituted the treatment group**, whereas** non-cultivating households constituted the comparison group**.** The purpose of the PSM analysis was to compare outcomes between these groups after statistically matching households with similar observable pre-treatment characteristics.

2.7 Binary Logistic Regression Model for Determinants of Enset Cultivation

A binary propensity-score model was used to estimate each household's probability of cultivating enset conditional on observed pre-treatment characteristics. The treatment indicator was coded 1 for enset cultivators and 0 for non-cultivators. Candidate covariates were selected on substantive grounds as characteristics that plausibly precede and influence both the cultivation decision and household outcomes. Variables that may themselves be consequences of enset cultivation should not be included in the primary propensity-score model.

The propensity score for household i is defined as: $P(X_i) = Pr(D_i = 1 \mid X_i)$

where D_i denotes enset cultivation, and X_i represents the vector of observed pre-treatment covariates.

The logit specification may be written as: $\ln[P_i/(1-P_i)] = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_k X_{ki}$

Propensity Score Matching (PSM) was employed to estimate the treatment effect of enset cultivation on daily calorie intake, HDDS, and annual household income. PSM is appropriate here because cultivation was not randomly assigned and cultivators and non-cultivators may differ systematically in observed characteristics. The analysis followed five stages: (1) estimation of propensity scores; (2) assessment of common support; (3) selection of a matching algorithm; (4) assessment of covariate

balance; and (5) estimation of the ATT. PSM can reduce imbalance in observed covariates but cannot remove bias arising from unobserved confounding.

Step 1: Estimation of propensity scores

The propensity-score model estimated the conditional probability of enset cultivation using observed pre-treatment household characteristics. The predicted probability for each household constituted its propensity score.

Step 2: Common support

The analysis was restricted to the region of common support, where treated and comparison households had overlapping propensity-score distributions. Observations outside the overlap region were excluded because a credible matched counterfactual could not be constructed.

Step 3: Matching algorithms

Nearest-neighbour, kernel, radius, and calliper matching were considered. Kernel matching with a bandwidth of 0.1 was selected in the current manuscript as the preferred specification because it reportedly provided favorable covariate balance while retaining a sufficiently large matched sample. The alternative algorithms should be retained as robustness checks.

Step 4: Covariate balance

Matching quality should be evaluated using standardized mean differences before and after matching. An absolute standardized difference below 0.10 is commonly used as an indication of acceptable balance. A propensity-score distribution plot and, preferably, a standardized-bias/Love plot should accompany the numerical diagnostics.

Step 5: Estimation of ATT

The principal estimand is the Average Treatment Effect on the Treated (ATT):

$$ATT = E[Y(1) - Y(0) \mid D = 1]$$

where Y(1) is the potential outcome for treated households under enset cultivation and Y(0) is the potential outcome that the same treated households would have experienced without cultivation.

ATT was estimated separately for daily calorie intake, HDDS, and annual household income. The final manuscript must report the point estimate, standard error, test statistic or p-value, and confidence interval for each outcome.

Robustness checks

The analysis should compare the preferred kernel estimate with estimates obtained from nearest-neighbour, radius, and calliper matching. Consistency in the direction and approximate magnitude of the estimates would strengthen the robustness assessment.

ATT was estimated separately for the principal outcomes:

- daily calorie intake;
- household dietary diversity score (HDDS); and
- annual household income.

The validity of the PSM estimates depends primarily on conditional independence (unconfoundedness) and common support. Conditional independence requires that, conditional on observed pre-treatment covariates, treatment assignment is independent of potential outcomes. Common support requires sufficient overlap in propensity scores. These assumptions are not directly testable from the observed data. Therefore, the estimated ATT should be interpreted as conditional on the observed covariates and matching specification, rather than as definitive experimental causality.

The validity of the PSM estimates depends primarily on two assumptions. First, conditional independence/unconfoundedness assumes that, conditional on the observed covariates included in the propensity-score model, potential outcomes are independent of treatment assignment. In practical terms, this means that relevant systematic differences between enset cultivators and non-cultivators are adequately captured by the observed covariates included in the model.

Second, the common-support or overlap assumption requires that households with comparable observed characteristics have a positive probability of both cultivating and not cultivating enset. The common-support restriction was therefore imposed before estimating the treatment effects.

PSM can reduce bias arising from observed differences between cultivators and non-cultivators; however, it cannot eliminate bias arising from unobserved characteristics that simultaneously influence enset cultivation and household outcomes. Therefore, the estimated ATT should be interpreted within the assumptions and limitations of the observational PSM framework. This qualification is particularly important when using the term **"effect."** The study estimates treatment effects under the PSM identifying assumptions rather than claiming that random experimental causality has been established.

The final diagnostic section should emphasize common support, standardized mean differences before and after matching, propensity-score overlap, matched sample size, and robustness across matching algorithms. The previously reported Breusch–Pagan/Cook–Weisberg test is not a central diagnostic for a binary propensity-score model and should not be used as evidence that the PSM model is adequate.

Several diagnostic procedures were undertaken to assess the reliability of the econometric analysis. **Multicollinearity** among explanatory variables was assessed using the Variance Inflation Factor (VIF). The VIF for each continuous explanatory variable was calculated as:

$$\text{VIF}(X_i) = \frac{1}{1-Ri^2} \quad \text{---------- (4)}$$

where R^2_i is the coefficient of determination obtained by regressing explanatory variable X_i on the remaining explanatory variables.

For the logistic regression, the manuscript should additionally report an appropriate goodness-of-fit **measure**, such as the likelihood-ratio test, pseudo-R^2 classification performance, and/or Hosmer–Lemeshow goodness-of-fit test, depending on what you actually estimated.

2.11 Descriptive Analysis

Descriptive statistics were used to characterize the sampled households and to compare enset cultivators and non-cultivators. Means, standard deviations, frequencies, and percentages were

calculated for continuous and categorical variables, respectively. Independent-sample t-tests were used to assess differences in the means of continuous variables between enset cultivators and non-cultivators, while chi-square (X^2) tests were used to examine associations between categorical variables. These descriptive comparisons were used to characterize the sample and identify initial differences between the two groups. They were not interpreted as causal effects, because observed differences between cultivators and non-cultivators may reflect systematic differences in household characteristics.

The analytical strategy was aligned with the study objectives. Descriptive statistics characterized the sample and documented initial differences between cultivators and non-cultivators. The propensity-score model estimated treatment assignment, while PSM estimated the ATT for daily calorie intake, HDDS, and annual household income. The binary food-security classification was treated as a secondary descriptive outcome unless its construction is fully documented and a separate binary-outcome ATT is available.

Table1. The analytical framework was structured to ensure consistency between the research objectives and the econometric methods.

Research objective	**Outcome/treatment**	**Analytical method**
Estimate the effect of enset cultivation on household food security	Daily calorie intake and overall food-security status	PSM/ATT
Estimate the effect of enset cultivation on household dietary diversity	HDDS	PSM/ATT
Estimate the effect of enset cultivation on household income	Annual household income	PSM/ATT
Identify factors associated with enset cultivation.	Enset cultivation (1 = cultivator; 0 = non-cultivator)	Binary logistic regression

This distinction is important because the logistic regression and PSM serve different analytical purposes. The logistic regression identifies factors associated with the probability of enset cultivation and generates the propensity scores, whereas PSM uses those scores to construct a comparable counterfactual group and estimate the treatment effect on the specified household outcomes.

The resulting binary food-security indicator was used as an outcome variable in the descriptive and econometric analyses. Importantly, daily calorie intake, HDDS, FCS, and household income were also retained as separate outcome measures where appropriate because they capture distinct

dimensions of household food security and economic well-being. Thus, the composite food-security classification provides an overall categorical measure, while the individual indicators allow the analysis to identify which specific dimensions differ between enset-cultivating and non-cultivating households.

3. RESULTS

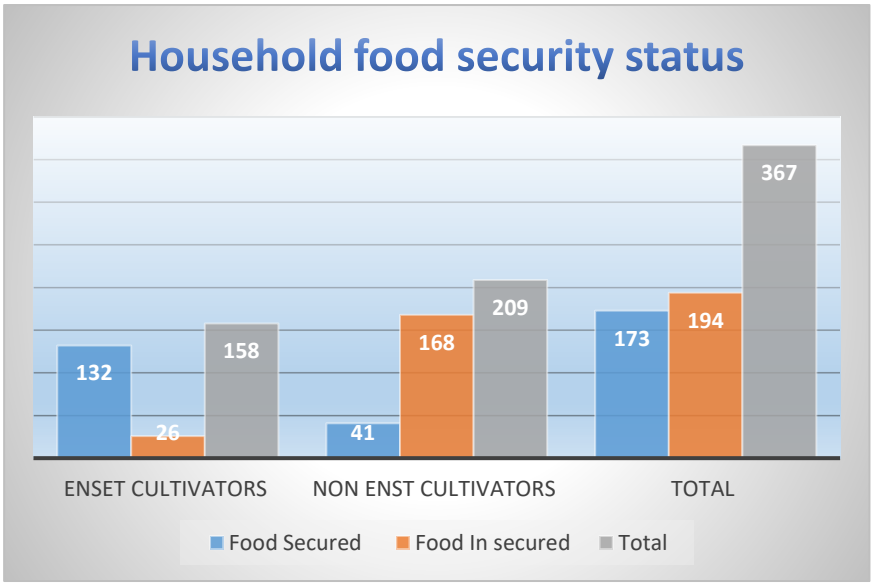
3.1. Descriptive Results

Descriptive statistics were used to characterize the sampled households and compare enset cultivators with non-cultivators. These comparisons describe observed group differences and are not interpreted as causal effects because treatment assignment was non-random.

3.1.1. Household Food-Security Status by Enset Cultivation

Among the 158 enset-cultivating households, 132 (83.5%) were classified as food secure and 26 (16.5%) as food insecure. Among the 209 non-cultivating households, 41 (19.9%) were classified as food secure and 168 (80.1%) as food insecure. These group-specific figures sum to 173 food-secure and 194 food-insecure households. The earlier statement reporting 162 food-secure and 205 food-insecure households is inconsistent with these group-specific counts and should be removed unless the original dataset confirms otherwise. The operational rule used to classify households should also be stated explicitly see Fig 2.

Figure 2: Household food-security status by enset cultivation



Household Daily Calorie Intake

As indicated Table on 2, daily calorie intake differed substantially between enset-cultivating and non-cultivating households. Enset cultivators had a mean daily energy availability of 2,531.95 kcal per adult equivalent, compared with 1,903.74 kcal per adult equivalent among non-cultivators. The unadjusted mean difference was 628.21 kcal/AE/day, with a reported t-value of −27.22 ($p<0.01$). This is a descriptive difference; the corresponding PSM ATT is required before interpreting the difference as an adjusted treatment effect.

Table 2: Mean difference in daily calorie intake between enset cultivators and non-cultivators

Daily Energy Available per AE in Kcal	**Enset cultivators (N=158)**	**Non-enset cultivators (N=209)**	**Total sample(N=367) Combined**	**t-value**
Maximum	3260	2650	3260	
Minimum	2100	1350	1350	-27.2224
Mean	2531.949	1903.737	2174.193	
Standard deviation	225.1057	214.1001	380.5377	
Mean difference	-628.212			

Note: Statistical significance at 10% (*), 5% (**) and 1% (***) probability levels.

Household Dietary Diversity Score (HDDS)

The descriptive distribution of household dietary diversity also differed between the two groups. Among enset cultivators, 44.30% had high HDDS (>6 food groups), compared with 7.18% among non-cultivators. Conversely, 48.80% of non-cultivators were in the low category (2–4 food groups), compared with 4.43% of cultivators. The mean HDDS was 2.40 among cultivators and 1.58 among non-cultivators, a difference of 0.815. The Pearson chi-square statistic was 114.204 ($p<0.001$). These results describe an association; the adjusted ATT for HDDS must be reported separately see Table 3.

Table 3: Household Dietary Diversity Score (HDDS) by Enset Cultivation

Total income	**Enset cultivators(N=158)**		**Non-Enset cultivators (N=209)**		**t-value**	**Pearson chi2(2)**
	Freq	%	Freq	%		
2-4 (Low)	7	4.43	102	48.80		
4-6 (Medium)	81	51.27	92	44.02	0.000***	114.2040
>6 (High)	70	44.30	15	7.18		
Mean	2.398734		1.583732			

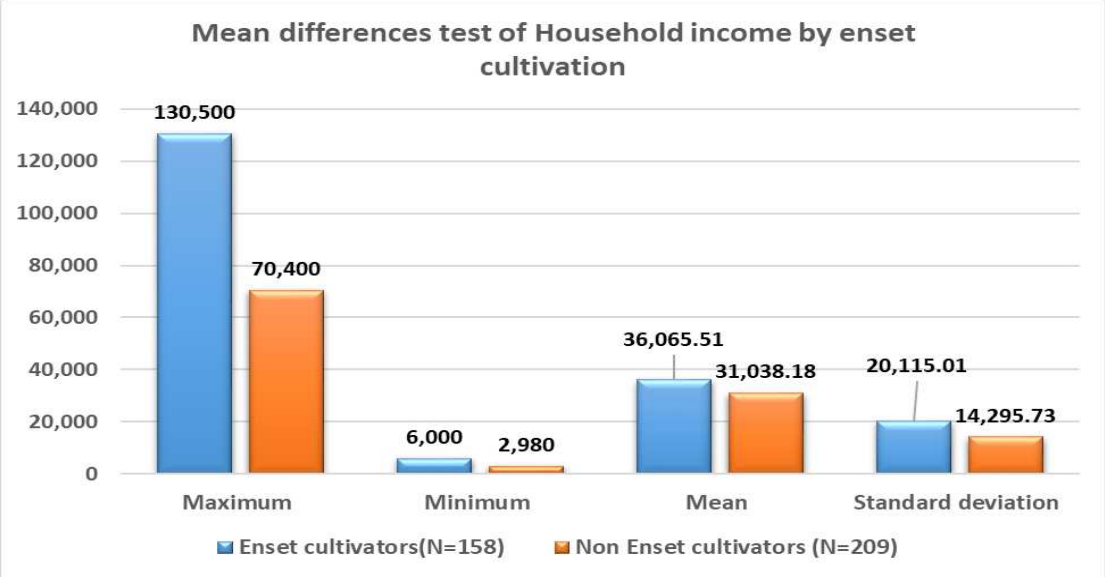
Standard deviation	0.5748428	0.6232078
Mean difference	0.815	

Household Income

Annual household income also differed descriptively. Mean annual household income was 36,065.51 ETB among enset cultivators and 31,038.18 ETB among non-cultivators, giving an unadjusted difference of 5,027.33 ETB. The reported t-value was −2.80. The PSM ATT should be used to quantify the adjusted difference under the matching assumptions see Fig 3.

The descriptive evidence therefore indicates higher reported calorie availability, dietary diversity, and annual income among enset cultivators. Because households were not randomly assigned to cultivation, these unadjusted differences may partly reflect differences in household characteristics. The PSM analysis is intended to reduce imbalance in observed pre-treatment covariates.

Figure 3: Mean difference in household income by enset cultivation



3.2. Propensity-Score Matching Analysis

The PSM analysis estimated the relationship between enset cultivation and three principal outcomes: daily calorie intake, HDDS, and annual household income. The treatment indicator was enset cultivation. The analysis restricted observations to common support, evaluated covariate balance, and estimated the ATT using alternative matching algorithms.

The propensity-score model should include only plausibly pre-treatment covariates. In particular, enset land size requires verification: if it represents land allocated to enset as a consequence of the cultivation decision, it is post-treatment and should not be used as a propensity-score covariate. The original estimation command/output should also be checked because the current coefficient table reports an F statistic, R-squared, Root MSE, and t statistics, which is not the conventional presentation of a binary logistic regression.

3.2.1. Propensity-Score Model Diagnostics

Multicollinearity Test

The reported VIF results indicate low collinearity among the candidate covariates: the highest VIF was 1.93 for total land size and the mean VIF was 1.34. These results indicate no substantial multicollinearity among the variables assessed, but VIF alone does not establish the adequacy of the propensity-score model see Table 4.

For the final PSM analysis, the principal diagnostic evidence should be the extent to which standardized covariate imbalance is reduced after matching. The manuscript reports that 16 covariates were balanced and that the post-matching pseudo-R^2 was 0.026. The actual pre- and post-matching standardized biases should be presented in a dedicated balance table or standardised-bias plot.

Table 4: Variance Inflation Factors (VIF) of the explanatory variables

Variable	VIF	1/VIF
Total lands	1.93	0.518134
Enset land	1.74	0.574712
Experience	1.64	0.609755
Pests and Diseases	1.55	0.645161
Shortage of	1.47	0.680272
Climate change	1.32	0.757575
Age	1.27	0.787401
Access to credit	1.23	0.813008
Education	1.21	0.826446
Access to Ext	1.11	0.909090
Sex	1.09	0.917431
Marital Status	1.06	0.943396
Total lives	1.04	0.961538
HH Size	1.03	0.966429
Mean VIF	1.34	

The previously reported Breusch–Pagan/Cook–Weisberg test and link test should not be used as the principal evidence for PSM adequacy. The final diagnostic section should instead emphasize common support, standardized mean differences, propensity-score overlap, matched sample size, and robustness across matching algorithms.

The Breusch–Pagan/Cook–Weisberg test produced a chi-square value of 0.55 with p=0.4574. The null hypothesis of constant variance therefore could not be rejected at the 5% significance level. A link test was also conducted to assess model specification. The predicted value (_hat) was statistically significant (p<0.001), whereas the squared predicted value (_hatsq) was not statistically significant (p=0.841). Within the reported diagnostics, these results provide no evidence of a major specification problem see Table 5.

Table 5: Link test of model specification

Enset cultivation practices	**Coefficient**	**Std. err.**	**z**	**P>z**	**[95% conf.**	**interval]**
_hat	1.002301	.1897277	5.28	0.000	.6304413	1.37416
_hatsq	-.0105203	.0524555	-0.20	0.841	-.1133311	.0922906
_cons	.0382336	.4056148	0.09	0.925	-.7567568	.8332239

3.2.2. Propensity-Score Model and Treatment Assignment

The propensity-score model was used primarily to estimate the probability of enset cultivation rather than to explain household food-security status. The current manuscript reports associations for education, total land size, enset land size, farming experience, extension access, credit access, pests and diseases, climate-change perception, shortage of agricultural land, and sex at the 10% level. These should be interpreted as associations within the treatment-assignment model, not as causal determinants.

A binary logistic regression model was estimated to identify factors associated with household participation in enset cultivation. The dependent variable was enset cultivation, coded 1 for cultivators and 0 for non-cultivators. Fourteen explanatory variables were included based on theoretical considerations and the empirical literature. This model should be distinguished from a food-security model: its purpose in the present analysis is to explain treatment assignment and generate the propensity scores subsequently used in the PSM analysis.

Table **6**: Binary Logistic regression model output

	Coefficient	**Std. err.**	**t**	**P>t**	**[95% conf.**	**interval]**
Sex	-.0501686	.0289768	-1.73	0.084*	-.107158	.0068209
Age	-.0081093	.0178457	-0.45	0.650	-.0432069	.0269883
Marital	-.0021635	.0171742	-0.13	0.900	-.0359406	.0316135
Education	.0666355	.0148891	4.48	0.000***	.0373528	.0959182
HH Size	-.0019303	.005078	-0.38	0.704	-.0119174	.0080567
Total land size	.023132	.010596	2.18	0.030*	.0022925	.0439715
Enset land	.0708077	.0218453	3.24	0.001**	.0278439	.1137716
Experience	.0074473	.0016869	4.41	0.000***	.0041295	.0107651
Access to Extension	.1021265	.0266996	3.83	0.000***	.0496157	.1546373
Access to credit	.0572258	.0277085	2.07	0.040*	.0027308	.1117208
Total livestock	-.0041341	.0055769	-0.74	0.459	-.0151024	.0068343
Pests and Diseases	.3322367	.031628	10.50	0.000***	.270033	.3944403
Climate change	.1648235	.0283825	5.81	0.000***	.1090029	.2206442
Shortage of Land	.1923253	.0288998	6.65	0.000***	.1354873	.2491632
_cons	-.3554839	.0723986	-4.91	0.000	-.497872	-.2130958

Source	SS	df	Ms	Number of obs	= 367
				F (15,351)	= 105.81
Model	73.6827621	15	4.91218414	Prob > F	= 0.0000
Residual	16.29543996	351	0.046425754	R-squared	= 0.2189
Total	89.9782016	366	0.245842081	Root MSE	= 0.21547

***, ** and* means significant at 1%, 5% and 10% probability levels, respectively

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3.2.3. Estimation of Propensity Scores

The estimated propensity score represents the conditional probability that a household cultivates enset given the observed covariates. The reported propensity-score ranges were 0.05213–0.952295 for enset cultivators and 0.029421–0.897623 for non-cultivators see Table 7.

3.2.4 Common Support

The analysis imposed the common-support condition by excluding observations without adequate overlap between treated and comparison propensity-score distributions. The manuscript reports that

26 observations were discarded. After trimming, 141 enset cultivators and 193 non-cultivators remained in the matched analysis.

Table 7: Distribution of estimated propensity scores matching between cultivators and non- cultivators

Group	Obs	Mean	Std. Dev	Min	Max
Enset cultivation practices	158	0.569217	0.2400916	0.05213	0.952295
Non-cultivation practices	209	0.378891	0.1814766	0.029421	0.897623
Total Household	367	0.4305177	0.2351019	0.018936	0.973119

Figure 4 illustrates the distribution of propensity scores for treated (enset-cultivating) and untreated (non-enset-cultivating) households before matching. The distributions indicate differences in the propensity-score profiles of the two groups before matching, which motivates the use of matching to improve comparability.

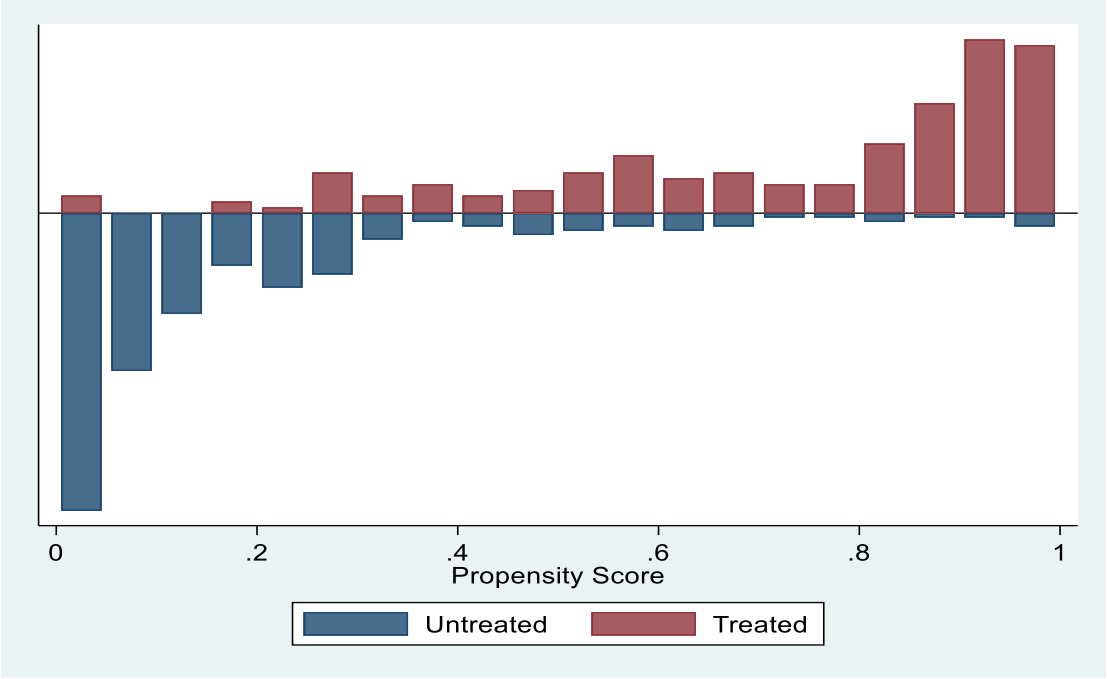


Figure 4. Propensity-score distribution before matching

Figure 5 illustrates the propensity-score distribution after restricting the analysis to the common-support region. The supported observations represent households for which comparable treated and untreated cases are available, whereas observations outside the support region are excluded from the matching analysis.

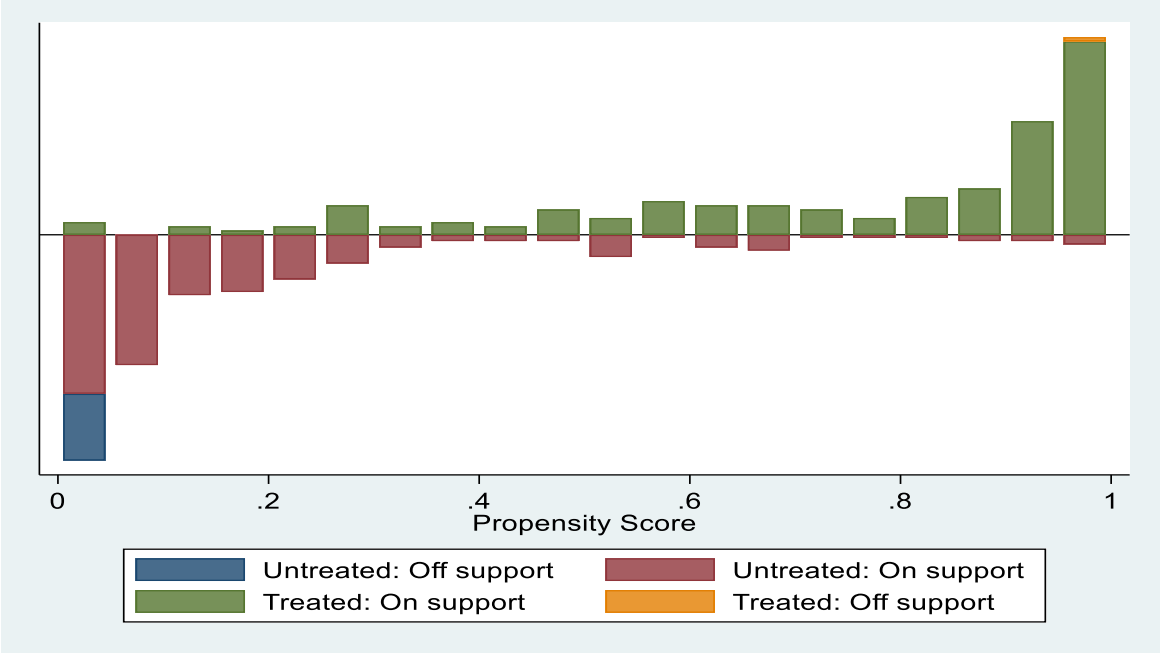


Figure 5. Propensity-score distribution after matching

3.2.5 Matching Algorithm and Covariate Balance

Nearest-neighbour, kernel, radius, and calliper matching were considered. Kernel matching with a bandwidth of 0.1 was selected in the current analysis as the preferred specification because it reportedly provided favorable covariate balance while retaining a relatively large matched sample. After common-support trimming, 141 treated households were matched with 193 comparison households. The reported post-matching pseudo-R^2 was 0.026 and 16 covariates were reported as balanced. The actual standardized-bias values before and after matching must be presented to substantiate this claim.

3.2.6 Estimated Treatment Effects (ATT)

The PSM results show that enset cultivation had a positive and statistically significant association with all three outcome variables. Enset-cultivating households had an estimated 226.44 kcal/AE/day higher intake than comparable non-cultivating households ($p < 0.001$). Enset cultivation was associated with a 0.324-point higher dietary diversity score ($p < 0.001$). Enset-cultivating households had approximately ETB 2,676 higher annual income than comparable non-cultivating households ($p = 0.006$) see Table 8.

Generally, the ATT estimates suggest that enset cultivation is positively associated with household food security and economic well-being among the treated households. Because the study uses

observational data and PSM, these results should be interpreted as estimated treatment effects conditional on the matching assumptions, rather than definitive causal effects.

Table: 8 The underlying ATT, SE, and t-statistics are report

Outcome	Matching method	ATT	Std. error	t/z	p-value	95% CI
Daily calorie intake (kcal/AE/day)	Kernel (bandwidth 0.1)	226.44	48.26	4.69	<0.001	131.85–321.02
HDDS	Kernel (bandwidth 0.1)	0.324	0.087	3.71	<0.001	0.153–0.495
Annual household income (ETB)	Kernel (bandwidth 0.1)	2,676.06	976.50	2.74	0.006	762.13–4,590.00

Note: 95% confidence intervals are calculated as ATT ± 1.96 × standard error.

3.3. Summary and Conclusion

This study examined the association between enset cultivation and household food security and economic well-being in Hadiya Zone using household survey data and propensity score matching. The analysis distinguishes descriptive group differences from adjusted treatment effects. The principal outcomes are daily calorie intake, household dietary diversity, and annual household income.

The study included 367 households, comprising 158 enset cultivators and 209 non-cultivators. Descriptive comparisons showed higher reported calorie availability, dietary diversity, and annual income among enset cultivators. Mean daily energy availability was 2,531.95 kcal/AE/day among cultivators and 1,903.74 kcal/AE/day among non-cultivators; mean HDDS was 2.40 and 1.58, respectively; and mean annual income was 36,065.51 ETB and 31,038.18 ETB, respectively. These descriptive differences should not be interpreted as causal effects because treatment assignment was non-random.

The reported PSM analysis restricted the sample to common support and retained 141 treated and 193 comparison households after 26 observations were discarded. Kernel matching with a bandwidth of 0.1 was selected as the preferred specification, and the manuscript reports a post-matching pseudo-R^2 of 0.026 with 16 covariates balanced. However, the numerical ATT estimates are not present in the current document. The conclusion should therefore not state the magnitude of treatment effects until the original ATT output is inserted and the corresponding confidence intervals and robustness estimates are verified.

The treatment-assignment model also requires technical verification. In particular, variables such as

enset land size should be retained only if they clearly represent pre-treatment characteristics. In addition, the current model-output table reports statistics characteristic of a linear regression rather than a conventional binary logistic regression, so the original statistical command and output should be checked before the model is labelled as logistic regression.

Subject to these analytical corrections and insertion of the numerical ATT estimates, the study can provide location-specific evidence on the relationship between enset cultivation and household welfare in Hadiya Zone. The findings should be framed as treatment-effect estimates under the PSM identifying assumptions rather than as evidence from a randomized experiment.

4.1 Policy and Research Implications

The study's descriptive evidence and final PSM estimates can inform extension and livelihood interventions related to enset-based farming. Recommendations should be tied directly to the verified empirical results. Future studies should use panel or longitudinal data where feasible, document treatment timing more clearly, and investigate potential unobserved confounding and heterogeneous treatment effects.

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Authors' contributions: This work was carried out in collaboration between the two authors. Author **one** contributed to supervision, review & editing, formal data analysis, project administration, Visualizations, Validation, and Conceptualization. Author two, software, data collection, investigation, writing the original draft, resources, and methodology

- **Data availability statement**: "The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request"
- **Ethics approval:** The Research Ethics Committee/Institutional Review Board of Wachemo University, Ethiopia, waived the requirement for formal ethical approval for this study in accordance with applicable institutional requirements. This determination is documented in the institutional letter (Ref. No. WCU.AVP 02/3570/25, dated 25 June 2025).
- **Ethical compliance:** The study was conducted in accordance with the applicable institutional and national research ethics requirements. The relevant ethical framework should be identified according to the regulations or guidelines applicable to the study

- **Consent to participate:** Verbal informed consent was obtained from all participants before data collection. All 367 respondents were aged 18 years or older at the time of participation
- **Secondary data:** Secondary information was used to supplement the primary household-level survey data. No participant consent is claimed to have been waived for secondary data unless such a waiver was applicable and documented
- **Consent to publish**: Consent for publication was not applicable because the manuscript does not contain personally identifiable information, images, or other details relating to identifiable individuals.
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