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Does guava (*Psidium guajava* L.) adoption enhance food security and dietary diversity? A neglected fruit crop from northern Ethiopia

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Abstract

This paper aimed to examine the impact of guava adoption on food security and dietary diversity of farm households in northern Ethiopia. This study used 384 sample households, of which 184 and 200 were adopters and non-adopters, respectively. We used an endogenous switching regression model (ESR) in the impact evaluation. From the first stage (selection) of model result, factors such as age of household head, farm size, livestock ownership, access to markets, access to irrigation, household income, and access to extension services significantly influences the likelihood of guava adoption. The result of the second stage of the endogenous switching regression model shows that adoption of guava has significantly enhanced household's food security (calorie intake) and dietary diversity score, by 2.15 % and 37.8 %, respectively. Furthermore, the positive sign of transitional heterogeneity effect highlights guava adopters had significantly greater food security status and dietary diversity score. Therefore, this study recommends that the regional government of Tigray should give particular attention to resource-poor farmers by strengthening institutional services, thereby fostering guava adoption as a strategic intervention to address food insecurity.

Keywords: endogenous switching regression, impact evaluation, transitional heterogeneity effect

1 Introduction

Food insecurity is a major challenge in sub-Saharan Africa. It is primarily driven by low agricultural production, climate variability, and a high population growth rates (Berhanu & Oljira Wolde, 2019; Bjornlund *el al.*, 2022; Lefe *el al.*, 2024). Furthermore, farm households' widespread dependence on cereal crops exacerbates their food insecurity levels (FAO, 2020; Wamwea & Culas, 2024). Despite its agricultural challenges, Ethiopia has enormous agricultural potential thanks to its extensive fertile farmland and diverse climate. This allows the country to cultivate a wide range of both annual and perennial crops (Lemenih & Kassa, 2018; Demie *el al.*, 2024).

Perennial crops, such as fruit trees, play a vital role in improving livelihoods and income sources in rural areas (Mengistu & Belda, 2024). In Ethiopia in particular, the cultivation of these perennial fruit crops is widespread, providing a significant source of income and food for rural households (Tesfay *el al.*, 2024).Guava (*Psidium guajava* L.), known locally as Zeytuhun, is one of the most important of these fruit crops. It is cultivated by more than 250,000 households nationwide, with an estimated average yield of around 8000 kg ha^{-1} (Ashinie, 2019). The guava is native fruit crop to southeast Mexico and Central America (Alba-Jiménez *el al.*, 2018) and is cultivated globally in subtropical and tropical countries, including India, Brazil, and Italy (Angulo-López *el al.*, 2021). It is also grown in several African countries, including Ghana, Eritrea, Kenya, and Ethiopia (Omayio *el al.*, 2020).

Guava is a versatile and strategic fruit crop, valued for its drought tolerance, nutritional density, and pharmacological properties. In Ethiopia, where diets are predominantly cereal-based, guava serves as an excellent supplementary food source (Islam *el al.*, 2020; Takeda *el al.*, 2023). Rich in vitamins A and C, fibre, iron, phosphorus, calcium, and other essential minerals, it is a nutrient-dense fruit (Naseer *el al.*, 2018). Its leaves have been used as green adsorbents

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for chromium removal, while aqueous extracts from both leaves and fruits have long been employed medicinally to treat ailments such as gastroenteritis, diarrhoea, dysentery, rheumatic pain, wounds, ulcers, hypertension, and toothache (Ramadan, 2019).

Integrating guava into farming systems enhances soil fertility, boosts household income through fruit sales, and improves dietary diversity making it a key crop in addressing food insecurity and malnutrition in Ethiopia (Urugo *el al.*, 2024). Its economic value is evident in local and regional markets (Tigray Bureau of Agriculture and Rural Development, 2023), and its resilience to drought, salinity, high temperatures, and elevated CO_2 levels makes it particularly suitable for Ethiopia's climate-stressed regions (Singh *el al.* 2017; Usman, 2023).

Despite its potential, empirical research on guava production remains limited. Most studies have focused on its physical, chemical, and nutritional attributes. Deißler *el al.* (2024) explored fruit tree adoption, including guava, but emphasised aspirations and income rather than food security. Gurib (2006) highlighted guava's nutritional value, yet evidence on its role in food availability, access, utilisation, and stability is scarce. Chanie *el al.* (2024) noted guava's contribution to rural incomes via agroforestry, though without assessing its direct impact on food security or income share. Gebremariam *el al.* (2019) linked fruit crop adoption to improved food security and income, but did not focus specifically on guava.

In northern Ethiopia, particularly Tigray, food insecurity and poor dietary diversity remain critical, with 30 % of the population facing extreme shortages (United Nations Office for the Coordination of Humanitarian Affairs, 2024) and over 38 % of children suffering chronic malnutrition (CSA & UNICEF, 2021). Guava's nutritional benefits, drought resilience, and market potential position it as a vital crop to address these challenges – yet its cultivation remains minimal.

This study aims to fill these gaps and unlock guava's full potential. It distinguishes itself in three key ways: (1) by assessing the direct impact of guava adoption on household food security and dietary diversity using the Endogenous Switching Regression model; (2) by examining socio-economic, institutional, and demographic factors influencing adoption, including income share from guava; and (3) by accounting for heterogeneity between adopters and non-adopters to inform broader agricultural policy. Ultimately, this research offers valuable insights for scholars and policymakers, promoting guava as a sustainable nutritional resource and enhancing community resilience in drought-prone Tigray region,Ethiopia.

2 Materials and methods

2.1 Study area

This study was conducted in Ahferom and Kilte-Awulaelo districts of Tigray region, Ethiopia, due to the production potential of guava (Tigray Bureau of Agriculture and Rural Development, 2023). Ahferom district is located between 14°20'00" N latitude and 39°10'00" E longitude, while Kilte Awlaelo is situated at about 13°45'00" N latitude and 39°30'00" E longitude. The livelihoods of the population in both districts are directly or indirectly dependent on agricultural activities (Ahferom Office of Agriculture and Rural Development, 2023). Mixed farming predominates in both areas. The major crops grown include barley, wheat, and teff, while the principal fruits cultivated are cactus, guava, and mango (Tigray Bureau of Agriculture and Rural Development, 2023).

2.2 Research design and sampling method

This paper employed mixed research design, integrating both quantitative and qualitative methods. Moreover, this study used cross-sectional data collected from September 1 to October 30, 2024.

A multi-stage sampling procedure was employed to identify guava adopters and non-adopters. Firstly, two potential districts – Ahferom and Kilte-Awlaelo – were selected based on the guava production potential. Secondly, in consultation with district agricultural experts, ten potential guava-producing kebeles[1] were identified. Thirdly, three sample kebeles from Ahferom district – May-suru, Endamariam and Sero – and three from Kilte-Awlaelo district – Genfel, Aynalem and Tsigereda – were randomly selected. Fourthly, a total of 384 sample households, were proportionally selected, comprising 184 adopters and 200 non-adopters (Table 1). The sample size of 384 households was determined using Cochran's(1977) formula for large populations, assuming a 95 % confidence level and a 5 % margin of error.

2.3 Sources of data and methods of data collection

Both qualitative and quantitative data were utilised in this study, drawing from primary and secondary sources. Primary data were collected through intensive fieldwork using four main tools: focus group discussions, key informant interviews, personal observation, and a household survey. A semi-structured questionnaire was developed for individual interviews and pre-tested to ensure its validity. Secondary data were obtained from the Agriculture and Rural

[1]Kebele is the smallest administrative unit in Tigray region, Ethiopia.

Table 1: *Sample size proportion of selected kebeles.*

District	*Kebeles*	*Adop.*	*N-Adop.*	*Total*
Kilte-Awlaelo	Genfel	28	32	60
	Aynalem	32	34	66
	Tsigereda	30	32	62
Ahferom	May-suru	35	38	73
	Endamariam	31	33	64
	Sero	28	31	59
Total		*184*	*200*	*384*

Note: Adop. = Adopters; N-Adop. = Non-adopters.

Development Offices of Kilte-Awlaelo and Ahferom districts, the Tigray Bureau of Agriculture and Rural Development, as well as relevant published and unpublished materials.

2.4 *Econometric model specification and estimation strategy*

An Endogenous Switching Regression (ESR) model was employed to estimate the impact of guava adoption on food security, while addressing both observed and unobserved selection biases. Selection bias may arise from differences in farmers' skills, access to information, or wealth status, which influence their likelihood of adopting guava. Additionally, self-selection into adoption introduces endogeneity. The ESR model is well-suited to account for these issues. This model is built upon household utility maximisation frameworks, which are common in agricultural impact studies (Singh *el al.* 1986).

Estimation of the ESR model has two steps: the first step is the selection (probit) model used to determine factors influencing guava adoption.

$$C_i^* = \alpha Z_i + \eta_i, \text{ where } C_i = 1 \text{ (Adopter) if } C_i^* > 0, \quad C_i = 0 \text{ (Non-adopter) if } C_i^* \leq 0. \tag{1}$$

where, C^* is the latent variable representing the propensity to adopt guava, α is a vector of coefficients, C_i is the variable represents the adoption status of the i-th household, Z_i is a vector of household characteristics; and η_i is a random error.

In the second step ESR model, two separate groups of food security functions are defined. Therefore, food security functions are given by:

$$\text{Regime 1: } Y_{1i} = \beta_1 X_i + \varepsilon_{1i} \quad \text{if } C_i = 1 \text{ (Adopters)} \tag{2}$$

$$\text{Regime 2: } Y_{2i} = \beta_2 X_i + \varepsilon_{2i} \quad \text{if } C_i = 0 \text{ (Non-adopters)} \tag{3}$$

Where Y_{1i} and Y_{2i} represent the food security (outcome) for guava adopters and non-adopters, respectively; X_i represents the vector of covariates of producer i; β_1 and β_2 are parameters to be estimated; and ε_{1i} and ε_{2i} are error terms. The coefficients from the ESR model allows to derive the average treatment effect on the treated (ATT). Specifically, the observed and unobserved counterfactual outcomes adoption of guava can be computed as:

$$E[Y_{1i} \mid A = 1] = \beta_1 X_i + \sigma_{1\eta}\lambda_{1i} \tag{4}$$

$$E[Y_{2i} \mid A = 0] = \beta_2 X_i + \sigma_{2\eta}\lambda_{2i} \tag{5}$$

$$E[Y_{2i} \mid A = 1] = \beta_2 X_i + \sigma_{2\eta}\lambda_{1i} \tag{6}$$

$$E[Y_{1i} \mid A = 0] = \beta_1 X_i + \sigma_{1\eta}\lambda_{2i} \tag{7}$$

Equation 4 computes the observed outcome for adopters (a) and equation 5 calculates the observed outcome for non-adopters (b). The expected outcome (c) in equation 6 represents the counterfactual for the observed outcome (a) in equation 4. These counterfactual expresses what would have happened had the farmers decided to be non-adopters. Similarly, equation 7 is a counterfactual outcome (d) for the observed outcome (b) in equation 5. It represents the scenario in which farmers decided to be adopters. Therefore, the average treatment effect on a treat (ATT) is the difference between a – c and the average treatment effect on untreated (ATU) which is the difference between d – b. Furthermore, the transitional heterogeneity effect is estimated using the formula (a–d) – (c–b).

2.5 *Measuring the food security*

Food security is measured by two parameters. The first measurement is the calorie intake (consumed food items) within consecutive seven days. To do this, based on EHNRI (1998), the bundle of food items that households consumed was enumerated and quantified in terms of 100 grams of solid food using conversion factors for liquid and semi-liquid food items. Accordingly, 2100 kcal d^{-1} is the minimum requirement for a unit adult equivalent in Ethiopia (Federal Democratic Republic of Ethiopia, 1996). The second measure is the dietary diversity score computed from each food item consumed and grouped into seven food groups[2] (FAO, 2007).

[2]The food groups that are used for calculating dietary diversity score are: (1) cereals, roots and tubers, (2) pulses and legumes, (3) dairy products (4) meats, fish and eggs (5) oils and fats (6) fruits, and (7) vegetables.

3 Results

3.1 Demographic and socio-economic characteristics of respondents

Adopters were younger and had slightly larger households than non-adopters (Table 2). They also owned more livestock and reported higher income levels. Additionally, educational attainment and farm size were marginally greater among adopters, who also had higher family sizes and dietary diversity scores. Furthermore, non-adopters remained below Ethiopia's food security threshold compared to adopters, confirming that guava adoption contributed to bridging caloric gaps.

Table 2: *Descriptive statistics of non-adopters (n=200) and adopters (n=184).*

	Non-adopters		Adopters	
Variable	*Mean*	*SD*	*Mean*	*SD*
Age in years	55	6.03	47	6.05
Family size in adult eq.	4.65	1.66	4.91	3.25
Education in years	2.41	3.70	3.07	3.78
Farm size in hectare	0.49	0.10	0.52	0.09
Guava land in hectare			0.14	0.02
Livestock ownership*	2.55	0.84	2.86	0.79
Distance to market (km)	2.29	1.12	2.12	0.87
Total income (ETB)	57939	1563	103700	2650
Food security†	1973.5	309.7	2646.7	380.3
Dietary diversity score	3.89	0.70	4.91	0.91

Note: eq. = equivalent; * in TLU - tropical livestock unit; †kcal d^{-1} per adult equivalent.
During the survey period, the average exchange rates were: 1 USD ≈ 116.32 ETB and 1 EURO ≈ 129. 56 ETB

3.2 Guava production and income share

Farmers in the study area operated on very small farms (0.4 – 0.6 ha). Adopters allocated about one-quarter of their land to guava, indicating a strong preference for the crop despite competing land uses (Table 2). The average annual production of guava was 563 kg per household. This translates to 4170 kg ha^{-1}, highlighting the high yield potential of guava as a fruit crop. Guava trees typically yield fruit up to three times per year, ensuring a steady supply in local markets. The average price of guava was about 32.50 ETB kg^{-1}. The average annual total income from all sources for the sample households was approximately 103,700 ETB. Of this, an average of 20,700 ETB was earned from selling guavas.

3.3 Econometric results

3.3.1 Probit model estimation results

The Probit model indicates that younger farmers with larger farms, more livestock, and better access to markets, irrigation, and extension services had a significantly higher probability of adopting guava (Table 3).

Table 3: *Probit model estimation for adoption of guava.*

Variables	*Marginal effect (dy/dx)*
Age of household head	−0.03 (0.01) ***
Sex of household head	0.13 (0.11)
Livestock ownership in TLU	0.15 (0.06) ***
Farm size in hectare	0.13 (0.02) ***
Education in years	0.01 (0.01)
Distance to market in km	−0.03 (0.04)
Extension service	0.27 (0.09) ***
Market access	0.43 (0.08) ***
Irrigation access	0.17 (0.09) *
Ln total income in ETB	0.94 (0.20) ***
Access to information	0.26 (0.11) **
LR $chi^2(12)$	348.68
Prob > chi^2	0.00
Observed probability	0.66
Predicted probability	0.39
Number of observations	384

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Standard errors in parentheses.

3.3.2 An endogenous switching regression estimation result

The result of Endogenous Switching Regression (ESR) model is presented in table S1 in the supplement. The educational attainment, annual income, access to market, and irrigation significantly determines guava adopters calorie intake. In addition, dietary diversity score of the adopters was influenced by farm size, educational attainment, extension service, irrigation, and annual income.

Adopters consumed about 2 % more calories and had 38 % higher dietary diversity scores than they would have without adoption. Non-adopters would also have gained from adoption, with expected dietary diversity improvements of about 23 % (Table 4). In addition, the analysis reveals significant base heterogeneity (BH_1). Adopters inherently possessed greater food security (0.30) and dietary diversity (1.04) than non-adopters even without the technology. However, if universally adopted (BH_2), this inherent advantage shrinks to 0.03 and 0.58, respectively. The gap between BH_1 and BH_2 showed that the technology itself reduces the inherent advantage of the adopter group.

Table 4: *Average Treatment Effect on Treated (ATT) and Average Treatment Effect on Untreated (ATU).*

Decision stage	*Group*	*Adopters*	*Non-adopters*	*Treatment effect (effect %)*
Ln food security	Adopters	(a) 7.87	(c) 7.71	ATT = (a - c) = 0.16** (2.15%)
	Non-adopters	(d) 7.57	(b) 7.68	ATU = (d - b) = −0.11*** (1.53%)
Heterogeneity effects	BH_1 ln(Calv) = 0.30		BH_2 ln(Calv) = 0.03	0.27***
Dietary diversity	Adopters	(a1) 4.92	(c1) 3.57	ATT = 1.35*** (37.80%)
	Non-adopters	(d1) 3.88	(b1) 2.99	ATU = 0.89*** (22.93%)
Heterogeneity effects	BH_1HHdd = 1.04		BH_2HHdd = 0.58	0.46***

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

4 Discussion

The impact of guava adoption on nutritional outcomes, such as calorie intake and dietary diversity, was significant. In turn, guava adoption was influenced by resource endowment (e.g., farm size, livestock, and income) and institutional support (e.g., extension services, market access, and irrigation).

Farm size, livestock ownership, and household income emerged as key factors influencing guava adoption, underscoring the importance of household resource endowment. Specifically, larger farms provided the flexibility to diversify into high-value crops like guava without compromising food security. This result aligned with the findings of Nakano & Otsuka (2023) in Kenya and Saadu *el al.* (2024) in Nigeria. Livestock ownership contributed additional liquidity, enabling households to invest in inputs such as seeds and fertilisers. A similar result was reported in the case of groundnut adoption in eastern Ethiopia by Mesfin *el al.* (2016) and fruit crop adoption in other parts of Ethiopia by Gebremariam *el al.* (2019). Higher total household income similarly facilitated adoption by providing the necessary financial buffer to manage risk and maintain perennial crops. These findings were consistent with those of Alamu *el al.* (2018), Nakano & Otsuka (2023), and Saadu *el al.* (2024) in sub-Saharan Africa.

Furthermore, access to extension services, markets, and irrigation significantly determined adoption. This underlined that shifting to high-value crops like guava required supportive institutions that reduced farming risks and fostered resilient and profitable livelihoods. Access to extension services provided essential technical knowledge, built farmer capacity, and encouraged guava adoption. This finding coincided with Alamu *el al.* (2018), who reported that extension visits enhanced fruit crop adoption in central Ethiopia. Access to market information was equally vital, as it ensured commercial viability and reduced risks for smallholders. Similarly, Gebremariam *el al.* (2019) noted that irrigation access increased crop diversification in drought-prone areas of Ethiopia.

Finally, the significant improvement in food security and dietary diversity among guava adopters demonstrated its role as a buffer against hunger and malnutrition. This result was consistent with earlier findings by Mengistu & Tsehay (2021) in Ethiopia and Tobin & Thiede (2019) in sub-Saharan Africa. Additionally, the base heterogeneity (BH) effect indicated that adopters were inherently better off in terms of food security and dietary diversity even before adoption, suggesting they had pre-existing advantages. However, if guava cultivation were universally adopted, this inherent gap between adopters and non-adopters would significantly narrow. This underlined that the technology primarily benefited less-advantaged households, effectively reducing pre-existing inequalities. Similarly, Patel *el al.* (2023) emphasized that effective agricultural policy required acknowledging the heterogeneity among farmers.

5 Conclusion

This study concludes that guava adoption is driven by a combination of household resource endowment and institutional support, leading to significant nutritional benefits. Notably, adoption improves food security and dietary diversity. A pivotal new finding is that while early adopters have inherent advantages (individual difference), widespread adoption would substantially narrow this nutritional gap, primarily benefiting less-advantaged households. Therefore, the government of Tigray, Ethiopia and other development agents must proactively target resource-poor farmers with contextual institutional support to ensure guava adoption, thereby fulfills its potential as an inclusive strategy for building resilient and nutritious livelihoods. However, while the study offers robust insight into the impact of guava adoption on food security and dietary diversity, it leaves a significant research gap unexplored. Longitudinal analysis on the sustainability of guava farming over time, particularly under variable climatic conditions or fluctuating market prices is an open question for other researchers.

Supplement

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Conflict of interest

The authors declare that they have no conflict of interest.

References

Ahferom Office of Agriculture and Rural Development (2023). Agriculture and Rural Development Annual Report.

Alamu, O., Osewa, S., & Sangotegbe, N. (2018). Influence of Agricultural Extension Delivery on Adoption of Fruit Crop Technologies: A Case Study of Ogbomoso Mango Production. *Greener Journal of Agricultural Sciences*, 8(9), 203–208. doi: 10.15580/gjas.2018.9.052316096.

Alba-Jiménez, J. E., Benito-Bautista, P., Nava, G. M., Rivera-Pastrana, D. M., Vázquez-Barrios, M. E., & Mercado-Silva, E. M. (2018). Chilling injury is associated with changes in microsomal membrane lipids in guava fruit (*Psidium guajava* L.) and the use of controlled atmospheres reduce these effects. *Scientia Horticulturae*, 240, 94–101. doi: 10.1016/j.scienta.2018.05.026.

Angulo-López, J. E., Flores-Gallegos, A. C., Torres-León, C., Ramírez-Guzmán, K. N., Martínez, G. A., & Aguilar, C. N. (2021). Guava (*Psidium guajava* l.) fruit and valorization of industrialization by-products. *Processes*, 9(6), 1–17. doi: 10.3390/pr9061075.

Ashinie, S. K. (2019). Horticultural Crops Research and Development in Ethiopia: Review on Current Status. *Journal of Biology, Agriculture and Healthcare*, 9(13), 1–14. doi: 10.7176/jbah/9-13-01.

Berhanu, M., & Oljira Wolde, A. (2019). Review on Climate Change Impacts and its Adaptation strategies on Food Security in Sub-Saharan Africa. *Agricultural Social Economic Journal*, 19(3), 145–154. doi: 10.21776/ub.agrise.2019.019.3.3.

Bjornlund, V., Bjornlund, H., & van Rooyen, A. (2022). Why food insecurity persists in sub-Saharan Africa: A review of existing evidence. *Food Security*, 14(4), 845–864. doi: 10.1007/s12571-022-01256-1.

Chanie, H. D., Kebede, B. Y., Debele, B. M., & Gelaw, M. A. (2024). Impact of integrated land management technology adoption on rural livelihoods in the Goyrie watershed, Southern Ethiopia: Endogenous switching regression modeling estimation. *Cogent Social Sciences*, 10(1). doi: 10.1080/23311886.2024.2391532.

Cochran (1977). Sampling Techniques. doi: 10.21608/alat.1977.222158.

CSA and UNICEF (2021). Ethiopia Demographic and Health Survey: Tigray Data.

Deißler, L., Mausch, K., Grote, U., Karanja, A., & McMullin, S. (2024). Aspirations, ambitions and the adoption of diverse fruit trees – a case study of the livelihood effects in Kenya. *Trees, Forests and People*, 16. doi: 10.1016/j.tfp.2024.100544.

Demie, G., Negash, M., Asrat, Z., & Bohdan, L. (2024). Perennial plant species composition and diversity in relation to socioecological variables and agroforestry practices in central Ethiopia. *Agroforestry Systems*, 98(2), 461–476. doi: 10.1007/s10457-023-00924-1.

Ethiopian Health and Nutritional Research Institute (1998). Conversion factors for liquid and semi-liquid food items. https://www.researchgate.net/publication/282204744 accessed via ResearchGate.

Federal Democratic Republic of Ethiopia (1996). Food Security Strategy Document.

Food and Agriculture Organization (2007). Guidelines for measuring household and individual dietary diversity. FAO and FANTA Project, Rome, Italy.

Food and Agriculture Organization (2020). The State of Food Security and Nutrition in the World. doi: 10.18356/63e608ce-en.

Gebremariam, T., Berhane, G., Kassa, B., & Yirga, C. (2019). Fruit crop adoption and food security in Ethiopia: Opportunities and challenges. *Food Security*, 11(3), 555–569. doi: 10.1007/s12571-019-00944-0.

Gurib-Fakim, A. (2006). Medicinal plants: Traditions of yesterday and drugs of tomorrow. *Molecular Aspects of Medicine*, 27(1), 1–93. doi: 10.1016/j.mam.2005.07.008.

Islam, N., Hossain, M. A., Rahman, M. M., & Sarker, M. A. (2020). Nutritional and economic significance of guava: A review. *Journal of Food Science and Technology*, 57(5), 1673–1684. doi: 10.1007/s11483-019-01692-x.

Kilte Awulaelo Office of Agriculture and Rural Development (2019). Agriculture and Rural Development Annual Report.

Lefe, Y. D. H., Asare-Nuamah, P., Njong, A. M., Kondowe, J., & Musakaruka, R. R. (2024). Does climate variability matter in achieving food security in Sub-Saharan Africa? *Environmental Challenges*, 15, 100870.

Lemenih, M., & Kassa, H. (2018). Resources of Ethiopia and their Development.

Mengistu, D. D., Degaga, D. T., & Tsehay, A. S. (2021). Analyzing the contribution of crop diversification in improving household food security among wheat dominated rural households in Sinana District, Bale Zone, Ethiopia. *Agriculture & Food Security*, 10, 1–15. doi: 10.1186/s40066-020-00280-8.

Mengistu, N. A., & Belda, R. H. (2024). The role of livelihood diversification strategies in the total household income in Takusa Woreda, Amhara Region, Ethiopia. *Cogent Social Sciences*, 10(1). doi: 10.1080/23311886.2024.2306033.

Mesfin, H. M., Ahmed, M. H., & Abady, S. (2016). Determinants of multiple groundnut technology adoption in Eastern Ethiopia. *Review of Agricultural and Applied Economics (RAAE)*, 19(2), 51–60. doi: 10.15414/raae/2016.19.02.51-60.

Nakano, Y., & Otsuka, K. (2023). Farm size and crop innovation: Evidence from Kenya. *Journal of Development Studies*, 59(1), 95–112.

Naseer, S., Hussain, S., Naeem, N., Pervaiz, M., & Rahman, M. (2018). The phytochemistry and medicinal value of *Psidium guajava* (guava). *International Journal of Phytomedicine and Phytotherapy*, 4(1), 32. doi: 10.1186/s40816-018-0093-8.

Omayio, D. G., Abong', G. O., Okoth, M. W., Gachuiri, C. K., & Mwang'ombe, A. W. (2020). Trends and Constraints in Guava (*Psidium guajava* L.) Production, Utilization, Processing and Preservation in Kenya. *International Journal of Fruit Science*, 20(3), 1–12. doi: 10.1080/15538362.2020.1791304.

Patel, A., Johnson, L., Kim, R., & Thompson, J. (2023). Understanding Heterogeneity in Agricultural Interventions: Implications for Policy. *Development Studies*, 32(3), 315–346.

Ramadan, M. F. (2019). *Fruit Oils: Chemistry and Functionality*. Springer, Cham. doi: 10.1007/978-3-030-12473-1.

Saadu, B., Ibrahim, H. Y., Nazifi, B., & Mudashiru, A. (2024). Adoption of climate-smart agricultural practices and its impact on smallholder farming households in some rural areas of North-Western Nigeria. *Agricultura Tropica et Subtropica*, 57(1), 23–34. doi: 10.2478/ats-2024-0003.

Singh, I., Squire, L., Strauss, J., & Bank, W. (1986). *Agricultural household models: extensions, applications, and policy*. World Bank. doi: 10.2307/1242324.

Takeda, L. N., Laurindo, L. F., Guiguer, E. L., Bishayee, A., Araújo, A. C., Ubeda, L. C. C., Goulart, R. d. A., & Barbalho, S. M. (2023). *Psidium guajava* L.: A Systematic Review of the Multifaceted Health Benefits and Economic Importance. *Food Reviews International*, 39(7), 4333–4363. doi: 10.1080/87559129.2021.2023819.

Tesfay, A., Tewolde-Berhan, S., Birhane, E., Rannestad, M. M., Gebretsadik, A., Hailemichael, G., Haile, M., & Gebrekirstos, A. (2024). Edible indigenous fruit trees and shrubs in Tigray, Ethiopia. *Trees, Forests and People*, 16, 100525. doi: 10.1016/j.tfp.2024.100525.

Tigray Bureau of Agriculture and Rural Development (2023). Report on fruit production and Productivity.

Tobin, D., Jones, K., & Thiede, B. C. (2019). Does crop diversity at the village level influence child nutrition security? Evidence from 11 sub-Saharan African countries. *Population and Environment*, 41(2), 74–97. doi: 10.1007/s11111-019-00327-4.

United Nations Office for the Coordination of Humanitarian Affairs (2024). Nutrition Situation in Tigray Region, Ethiopia. doi: 10.1163/_afco_asc_2528 accessed via OCHA Reports.

Urugo, M. M., Yohannis, E., Teka, T. A., Gemede, H. F., Tola, Y. B., Forsido, S. F., Tessema, A., Suraj, M., & Abdu, J. (2024). Addressing post-harvest losses through agro-processing for sustainable development in Ethiopia. *Journal of Agriculture and Food Research*, 18, 101316. doi: 10.1016/j.jafr.2024.101316.

Usman, M. (2023). Enhancing Climate Change Resilience in Guava (Psidium Species). In *Cultivation for Climate Change Resilience, Volume 1* (pp. 191–226). CRC Press. doi: 10.1201/9780429055584-12.

Wamwea, A., & Culas, R. J. (2024). Enhancing Food Security Through Climate-Smart Agriculture in Kenya. In *Climate-Smart and Resilient Food Systems and Security* (pp. 259–280). Springer volume 3. doi: 10.1007/978-3-031-65968-3_10.