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From adaptation to resilience: The impact of climate change adaptation on food security in Lamongan, Indonesia

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A B S T R A C T

Food security remains one of the most critical challenges in agrarian economies increasingly exposed to the adverse impacts of climate change. This study aims to analyze the determinants of climate change adaptation among farming households in East Java, Indonesia, and to assess its impact on household food security. Specifically, the research identifies the socio-economic and demographic factors influencing adaptation decisions and evaluates how these strategies affect food security outcomes. A multi-stage sampling approach was applied, and data were analyzed using a Probit model to determine the factors influencing adaptation, while Propensity Score Matching (PSM) was employed to estimate its causal effects on food security indicators. The findings reveal that education, secure land tenure, and membership in farmer groups significantly increase the likelihood of adopting adaptation measures, whereas greater farming experience, larger household size, and engagement in off-farm employment reduce it. Furthermore, adaptation was found to enhance dietary diversity and nutritional quality, as reflected in higher Food Consumption Scores, and to reduce the frequency of food insecurity experiences measured through the Food Insecurity Experience Scale. Overall, the study demonstrates that adaptation strengthens both objective and experiential aspects of food security, providing vital evidence for policy design aimed at promoting adaptive capacity and rural resilience in climate-vulnerable regions.

1. Introduction

Food security remains one of the central global challenges in the twenty-first century. It is defined by the Food and Agriculture Organization (FAO) as a condition in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food to meet their dietary needs for an active and healthy life (FAO, 2024). This concept is multidimensional, encompassing the aspects of availability, access, utilization, and stability (Hassoun et al., 2025). In developing countries such as Indonesia, food security is deeply intertwined with agriculture, which forms the backbone of the economy and employs a significant proportion of the labor force (Reardon & Timmer, 2014). The urgency of ensuring food security has been amplified by rapid population growth, the continuing decline in arable land due to urbanization and industrial expansion, and the intensification of climate change. These combined pressures mean that food security is no longer a matter of agricultural production alone, but one that concerns the resilience of socio-economic systems and the sustainability of rural livelihoods (Béné, 2020; Bullock et al., 2017).

Indonesia, as an agrarian country, faces unique vulnerabilities in this regard. The agricultural sector plays a vital role not only in providing national food supply but also in sustaining employment and supporting rural welfare. However, the sector is increasingly exposed to risks associated with climate change, such as prolonged droughts, unpredictable rainfall, floods, and soil degradation (Pickson et al., 2022). These risks undermine productivity and disrupt the continuity of food supply. At the same time, agricultural land in Indonesia has been shrinking at an alarming pace, which further exacerbates the threat to food self-sufficiency. This scenario underlines the urgency for adaptive measures to safeguard household and national food security, making it a strategic issue for both development and national resilience (Addi et al., 2025).

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The main research problem in this context lies in understanding how farming households respond to climate change and what factors drive their adaptation decisions. Despite the availability of technological innovations and government initiatives, the adoption of climate change adaptation measures varies widely among farming households (Raymond & Robinson, 2013). Some households are able to diversify crops, change planting calendars, or adopt new irrigation systems, while others remain unable to adapt due to socio-economic, institutional, or informational constraints (Magesa et al., 2023; Nugroho et al., 2022). The inconsistency in adoption raises a critical question: what determines whether a household adapts or not? Addressing this question is vital because adaptation is increasingly recognized as a key strategy for sustaining agricultural productivity and ensuring food security under changing climatic conditions.

A second dimension of the research problem involves the impact of adaptation on food security outcomes. While adaptation is often promoted as a solution to mitigate the adverse effects of climate change, empirical evidence on its effectiveness at the household level remains limited. Specifically, questions remain as to whether adaptation strategies improve household food security in terms of both dietary quality and the lived experience of food access (Hilemelekot et al., 2021). Policymakers, practitioners, and scholars need robust evidence on the causal relationship between adaptation and food security to design interventions that effectively enhance household resilience. Without such evidence, policies risk being based on assumptions rather than grounded in empirical realities (Singh et al., 2016).

Scholars have proposed a variety of general solutions to address these challenges. At the global level, the literature suggests that adaptation requires an enabling environment in which households are supported by adequate access to information, credit, extension services, and institutional support systems (Hanani AR et al., 2024; Pickson et al., 2022). Furthermore, promoting collective action through farmer groups and cooperatives has been highlighted as a pathway to reduce individual risks and costs (Seaman et al., 2014). These institutional arrangements can enhance access to resources and knowledge while providing a platform for the dissemination of climate-resilient technologies. Strengthening rural infrastructure and improving market linkages are also considered key general solutions to build resilience against climate shocks.

More specifically, recent empirical studies demonstrate that adaptation decisions are influenced by household socio-economic characteristics such as education, farming experience, and income, as well as institutional factors including access to extension services and credit (Burnham & Ma, 2017; Rahman et al., 2021). For example, farmers with higher levels of education are more likely to understand climate risks and adopt appropriate adaptation strategies. Similarly, households with access to credit and extension services tend to be better positioned to implement costly or complex adaptation measures. The literature also emphasizes the role of farmer group membership in enhancing adaptive capacity through collective learning and resource sharing. These specific solutions highlight that adaptation is not merely a technical process but a socio-institutional one, requiring a holistic understanding of both household and systemic determinants.

Previous studies have made important contributions to understanding adaptation and food security but have also left significant gaps. Research in Sub-Saharan Africa and South Asia, for instance, has shown that adaptation can improve dietary diversity, yet its effects on reducing food insecurity experiences are inconsistent (Kerr et al., 2019; Yolchi & Wang, 2025). Some studies suggest that while adaptation enhances food availability and utilization, it does not always translate into improved access, particularly when market and income constraints remain unaddressed. empirical research has often been limited to descriptive analyses of adaptation practices without adequately examining their causal impact on food security outcomes, include in Indonesia (Akmalia, 2022; Thompson et al., 2010; Tirado, Clarke et al., 2010). Moreover, most studies rely on a single food security indicator, which fails to capture the full complexity of household food security (Brüssow et al., 2017; Ogundeji, 2022). The reliance on either consumption-based measures or experiential measures alone provides only a partial picture, leaving the interaction between adaptation and multiple dimensions of food security underexplored.

The research gap, therefore, lies in systematically analyzing both the determinants of climate change adaptation decisions and the causal impact of adaptation on household food security using robust econometric methods. By employing a Probit model to identify the drivers of adaptation and a Propensity Score Matching (PSM) approach to estimate its causal impact, this study aims to fill that gap. The dual use of Food Consumption Score (FCS) and Food Insecurity Experience Scale (FIES) as complementary indicators provides a comprehensive assessment of food security outcomes, combining dietary quality with the lived experiences of food insecurity. This study is guided by two primary objectives: (1) to identify the factors determinant households' decisions to adopt climate change adaptation strategies, and (2) to measurement impact of adaptation on household food security, as measured by the Food Consumption Score (FCS) and the Food Insecurity Experience Scale (FIES)."

The contributions of this study are both academic and practical. Academically, the study adds to the literature by integrating socio-economic, demographic, and institutional determinants of adaptation with robust causal analysis of its impacts on food security. It advances methodological approaches in the Indonesian context by combining Probit and PSM analyses and by applying dual food security indicators for a more nuanced assessment. Practically, the findings provide evidence-based insights for policymakers and development practitioners seeking to strengthen household adaptive capacity and food security. The results can inform the design of targeted interventions such as improving access to extension services, credit, and farmer group participation, as well as supporting climate-resilient agricultural practices. By doing so, the study not only contributes to the academic discourse but also provides actionable recommendations for enhancing resilience and securing sustainable food systems in Indonesia.

2. Research Methode

2.1 Research Location and Data

This research was conducted in Lamongan District, East Java, Indonesia. According to the Central Bureau of Statistics (BPS), Lamongan is among the highest rice-producing areas in the province (BPS Jawa Timur, 2025). At the same time, the district is frequently affected by climate-related hazards such as droughts, irregular rainfall, and flooding. These conditions make Lamongan an appropriate site for examining the determinants and consequences of climate change adaptation among smallholder farmers, while also providing insights relevant to the broader Indonesian context where rural households remain highly dependent on agriculture yet vulnerable to climatic and structural challenges.

The study employed a multi-stage sampling design. At the first stage, East Java Province was purposively selected due to its significance as an agricultural region and its susceptibility to climatic shocks. At the second stage, Lamongan District was selected as the research site within East Java. At the third stage, two sub-districts—Tikungg and Maduran—were chosen to represent agro-ecological variation. Within each sub-district, two villages were selected, resulting in four villages in total. In each village, 50 farming households were randomly chosen, leading to a total sample of approximately 200 households. This approach ensured both geographic spread and adequate statistical power for econometric analysis.

The primary data were collected through a structured household survey administered directly to farming households. The survey instrument was comprehensive and designed to gather information on demographic characteristics, socio-economic profiles, agricultural practices, adaptation decisions, food consumption patterns, and institutional participation. To complement these primary data, secondary information was also drawn from official government reports, agricultural statistics, and local climate records. The combination of survey and secondary data strengthened the robustness of the analysis and provided contextual depth.

2.2 Measurement of Key Variables

2.2.1 Dependent Variables

The analysis employed two dependent variables to capture complementary dimensions of household food security: the Food Consumption Score (FCS) and the Food Insecurity Experience Scale (FIES).

a. Food Consumption Score (FCS): As developed by the World Food Programme (WFP), FCS is a composite indicator that integrates dietary diversity, frequency of food group consumption, and the relative nutritional value of those groups. It is calculated as a weighted sum of the number of days each of eight food groups was consumed during the previous seven days (WFP, 2023). A higher FCS denotes a more diverse and nutritionally adequate diet, whereas a lower score signals limited food diversity and potential insecurity.

b. Food Insecurity Experience Scale (FIES): Created by the FAO, FIES captures food insecurity using experiential indicators. It is based on responses to eight standardized questions reflecting experiences of uncertainty, anxiety, or deprivation in relation to food access. The responses allow for binary categorization into food secure versus insecure households (FAO, 2014). FIES provides an essential perspective by focusing on lived experiences of food insecurity, which complements the dietary information captured by FCS.

2.2.2 Independent Variables

The independent variables were grouped into socio-demographic, economic, and institutional domains, along with the central explanatory variable of adaptation.

a. Adaptation decision Households were classified as either adopters (coded 1) if they implemented at least one adaptation strategy in response to climate change, or non-adopters (coded 0) if they did not implement any strategy. This binary coding allows for clear econometric modeling of adaptation decisions.

b. Socio-demographic and economic variables: To estimate the determinants of adaptation, the Probit model incorporated the following explanatory factors: age of the household head, education level, farming experience, number of household members, size of landholding, off-farm income, ownership of livestock, status of land tenure, membership in farmer groups, engagement in secondary employment, access to credit, use of mobile banking services, and access to the internet. Each of these variables was selected based on theoretical and empirical grounds, as they are expected to influence household adaptive capacity through their effects on knowledge, resources, and access to information.

2.3 Estimation Strategy

The analytical approach consisted of two stages: first, examining determinants of adaptation through a Probit model, and second, estimating the causal impact of adaptation on food security outcomes using Propensity Score Matching (PSM).

2.3.1 Factor influencing adaptation climate change decision

Given that adaptation is a binary choice, a Probit model was specified to estimate the probability that a household adopts adaptation strategies. The model can be written as:

$$P(Adapt_i = 1|X_i) = \Phi(\beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_k X_{ik} + \varepsilon_i)$$

This equation can be broken down to understand its purpose. The left side, $P(Adapt_i = 1|X_i)$, represents the probability that a given household (i) will adopt an adaptation strategy, conditional on a set of explanatory variables (X_i). The right side of the equation uses the cumulative distribution function (Φ) of the standard normal distribution to transform a linear combination of variables into this probability. The linear combination itself, ($\beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_k X_{ik} + \varepsilon_i$), acts as an index or score. Here, β_0 is the intercept, β_1 through β_k are the coefficients to be estimated for each explanatory variable (X_{i1} through X_{ik}), and ε_i is the error term that accounts for unmeasured factors. The coefficients (β) themselves aren't directly interpretable as changes in probability. Therefore, the analysis calculates marginal effects to properly interpret the influence of each variable, showing how much a one-unit change in a variable impacts the probability of adoption.

2.3.2 Impact Climate Change Adaptation on Food Security

To evaluate the causal effect of adaptation on food security (FCS and FIES), PSM was employed to reduce selection bias. First, the propensity score was estimated using a Probit specification:

$$P(Adapt_i = 1) = \Phi(\gamma_0 + \gamma_1 X_{i1} + \gamma_2 X_{i2} + \cdots + \gamma_m X_{im} + \varepsilon_i)$$

where X_{i1} includes the covariates influencing adaptation decisions. Based on the estimated scores, households that adopted adaptation were matched with non-adopters using nearest-neighbor, kernel, radius and stratification matching. This matching ensured comparability between treatment and control groups.

The treatment effect of adaptation was then estimated as the Average Treatment Effect on the Treated (ATT):

$$ATT = E[Y_i(1) - Y_i(0)|Adapt_i = 1]$$

where $Y_i(1)$ is the observed food security outcome of an adopting household and $Y_i(0)$ is the counterfactual outcome had the same household not adopted. The ATT quantifies the gain in food security attributable to adaptation among households that actually adapted.

2.3.3 Robustness Checks

To verify reliability, balancing tests were applied to ensure covariates were similar across groups after matching. Standardized mean differences and kernel density distributions were examined. Sensitivity analyses using alternative matching methods were conducted to assess the stability of ATT estimates, thereby reinforcing the robustness of causal interpretations.

2.4 Ethical Considerations

The research strictly adhered to ethical standards. Approval was obtained from the appropriate institutional review board, and informed consent was secured from all respondents. Anonymity and confidentiality were guaranteed, and participants were informed of their right to withdraw at any stage. These protocols safeguarded the integrity of the study and the rights of participants.

3. Result and Discussion

3.1 Descriptive Statistics

The descriptive statistics offer an overview of the demographic and socio-economic conditions of the farming households. On average, the age of household heads was 51 years, indicating that most farmers are middle-aged and situated in a stage of life where decision-making capacity is relatively mature. The average level of formal education was 8.24 years, which shows that the majority of farmers had attained primary education and, in many cases, lower secondary schooling. This level of education plays a vital role in shaping their ability to access and interpret agricultural and climate-related information. Farming experience was substantial, with an average of almost 26 years, pointing to a deep engagement with agricultural practices over the long term. Household size averaged 2.71 persons, which reflects relatively small family units. Such demographic structure has implications for labor supply, as small households may face challenges in mobilizing adequate family labor for farm and adaptation activities. Average landholding was 1.13 hectares, consistent with the dominance of smallholder agriculture. Off-farm income contributed substantially to household livelihoods, averaging Rp30,300,000 per year, which highlights the significance of livelihood diversification strategies. Livestock ownership averaged 2.08 animals, providing both supplemental income and a buffer against production risks. In terms of tenure, 92 percent of households reported owning their land, which provides security and confidence for long-term investment in adaptive measures. Institutional variables also reveal interesting patterns. Membership in farmer groups was reported by 63 percent of respondents, pointing to the role of collective institutions in sharing knowledge and resources. Participation in off-farm work was noted among 64 percent of households,

reflecting that livelihood diversification is a common practice. However, only 9 percent of households had access to credit from formal institutions, underscoring the persistence of financial constraints. Mobile banking was used by 71 percent of households, and internet access was almost universal at 97 percent, indicating that digital technologies are now integral parts of rural life and offer important channels for dissemination of climate and market information.

Table 1
Statistic Descriptive

Variable	Descriptive Measurement	Mean	Std. dev.
Adaptation	Dummy decision climate change adaptation, minimal one strategy (1= yes; 0= otherwise)	0.49	0.50
Age	Age of household head (years)	51.07	11.39
Education	formal education (years)	8.24	2.86
Experience	Farming experience (years)	25.87	14.52
Household Size	Number of household members (persons)	2.71	1.14
Land Area	Size of cultivated farmland (hectares)	1.13	0.79
Income Off farm	Total household income from non-farm activities (Rp/year)	Rp30,300,000	Rp34,600,000
Livestock size	Number of livestock owned (heads)	2.08	3.05
Land Status	Dummy land ownership status (1 = owned; 0 = otherwise)	0.92	0.27
Group farm	Dummy Membership in farmer group (1=member; 0=otherwise)	0.63	0.49
Off farm work	Dummy Participation in off-farm work (1=yes; 0=otherwise)	0.64	0.48
Credi Acces	Dummy credit access from financial institutions (1=yes; 0=otherwise)	0.09	0.29
Mobile Banking	Dummy utilization of mobile banking services (1=yes;0=otherwise)	0.71	0.46
Internet	Dummy access to the internet (1=yes; 0=otherwise)	0.97	0.18
Food Consumption Score	Score of Food Consumption Score	41.45	10.35
Food Insecurity Experience Scale	Score of Food Insecurity Experience Scale	10.78	2.40

In terms of food security, the mean Food Consumption Score (FCS) was 41.45, which generally falls within the acceptable range and indicates adequate dietary diversity for most households. By contrast, the average Food Insecurity Experience Scale (FIES) score was 10.78, suggesting that while diets may be nutritionally adequate, households continue to face concerns and experiences of food insecurity in terms of stability, access, and affordability. Overall, these descriptive findings portray a profile of middle-aged and moderately educated farmers, with strong agricultural experience but constrained by small landholdings and limited access to formal credit. At the same time, the near-universal access to internet and high adoption of mobile banking highlight promising opportunities to support adaptation and resilience through digital and financial technologies. These characteristics frame the context in which the empirical results on adaptation decisions and food security outcomes should be interpreted.

3.2 Factor Determinant Climate Change Adaptation

The empirical results provide valuable insights into the determinants of climate change adaptation among farming households. Overall, the findings demonstrate that some factors positively influence the likelihood of adaptation, while others exert negative or constraining effects. The variables found to be statistically significant include education, farming experience, household size, land tenure status, group membership, and off-farm employment. These results highlight the multifaceted nature of adaptation decisions, reflecting the interplay of human capital, institutional structures, and livelihood strategies. In what follows, the discussion focuses exclusively on the significant variables, presenting the statistical evidence, providing justification, and situating the findings within academic debates and comparative literature.

Table 2
Factor Determinant Climate Change Adaptation

Adaptation	Coefficient	Std. err.	P>|z|
Age	0.011	0.015	0.461
Education	0.088	0.042	0.037**
Experience	-0.037	0.011	0.001***
Household Size	-0.206	0.093	0.026**
Land Area	0.150	0.137	0.271
Income Off farm	0.000	0.000	0.224
Livestock size	-0.035	0.037	0.344
Land Status	1.333	0.676	0.049**
Group farm	0.796	0.239	0.001***
Off farm work	-0.604	0.274	0.027**
Credi Acces	-0.349	0.381	0.36
Mobile Banking	-0.225	0.261	0.388
Internet	-0.700	0.564	0.214
_cons	-0.500	1.332	0.707
Pseudo R^2	0.280		

Note: ***,** significant at α 1% dan 5%

Education emerges as a positive and significant determinant of adaptation, with a coefficient of 0.088 and significance at the 5% level. This implies that each additional year of schooling increases the probability that a household will adopt climate

change adaptation practices. The justification for this finding lies in the fact that education enhances farmers' cognitive and analytical capacities, enabling them to better interpret climate information, evaluate the risks posed by climate change, and understand the potential benefits of adaptation strategies. Furthermore, education is strongly associated with greater access to extension services and the ability to adopt improved technologies. In the wider literature, numerous studies across Sub-Saharan Africa, South Asia, and Southeast Asia confirm the positive association between education and adaptation. For example Ogundeji (2022) and Rahman et al. (2022) reported similar positive effects. Yet, academic debate persists, with some scholars suggesting that higher education may encourage individuals to seek employment outside of agriculture, thereby reducing adaptation at the farm level. In this study, however, education reinforces adaptation, suggesting that educational attainment in the Indonesian context primarily equips farmers with skills and knowledge conducive to resilience rather than leading to exit from agriculture.

Farming experience, by contrast, shows a negative and highly significant effect, with a coefficient of -0.037 at the 1% level. This result indicates that farmers with longer experience are less likely to adopt new adaptation measures. One possible justification is that experienced farmers tend to rely heavily on traditional practices, which may result in inertia or resistance to innovation. Path dependency can limit openness to new technologies and practices, particularly when older methods have historically provided stability. This finding resonates with some studies in South Asia, where longer farming experience has been associated with more conservative behavior. For instance, studies in from Moerkerken et al. (2020) have shown that older, more experienced farmers may hesitate to adopt new approaches due to skepticism or risk aversion. Conversely, other studies, including from Rahman et al. (2021) argue that experience strengthens adaptive capacity by providing valuable knowledge of local climate variability. This divergence highlights an ongoing academic debate about whether farming experience should be considered an asset or a constraint in adaptation processes. In the Indonesian context, the evidence suggests that farming experience serves more as a barrier than a facilitator.

Household size is also negatively associated with adaptation, with a coefficient of -0.206 and significance at the 5% level. Larger households are less likely to implement adaptation strategies. A plausible explanation is that larger families place greater demands on household resources, increasing consumption needs while limiting funds available for adaptation investments. In addition, decision-making may become more complex within larger households, leading to delays or difficulties in implementing new practices. These results diverge which argue that larger households benefit from greater labor availability that can be mobilized for adaptation. For example, studies Hanani AR et al. (2024) suggest that larger family sizes support the adoption of labor-intensive strategies such as climate change preactice. However, imply that the resource constraints outweigh the potential labor advantages, underscoring the context-specific nature of household dynamics in shaping adaptation behavior.

Land tenure status exerts a strong positive effect, with a coefficient of 1.333 significant at the 5% level. Households with secure land rights are more likely to adopt climate adaptation strategies. Tenure security provides farmers with the confidence to invest in long-term practices such as soil fertility management, water conservation, or tree planting, as they are assured of reaping the benefits of their investments. Theoretical expectations and empirical evidence consistently support this finding. For instance, studies from Mogess and Ayen (2023) highlight land tenure as a fundamental determinant of sustainable land management and adaptation. Conversely, households without secure tenure face uncertainty, discouraging them from committing to adaptation measures. This study's finding reinforces the argument that land tenure reform is essential for enhancing adaptive capacity among smallholder farmers.

Group membership is another significant determinant, with a coefficient of 0.796 and significance at the 1% level. Participation in farmer groups substantially increases the probability of adopting adaptation practices. Farmer groups provide platforms for collective action, peer learning, and knowledge exchange, reducing the costs of accessing information and technologies. Through groups, farmers can also access credit, inputs, and extension services more effectively. Social capital thus plays a crucial role in adaptation processes. This result aligns with findings from numerous studies, including those by Hanani et al. (2025), which emphasize the role of collective institutions in promoting sustainable practices. Evidence from Indonesia similarly shows that group participation enhances the adoption of agriculture innovation strategy. However, some scholars caution that group membership can sometimes reinforce existing inequalities if benefits are concentrated among better-off households. In the Indonesian context, however, farmer groups appear to function inclusively, supporting widespread adaptation adoption.

Participation in off-farm employment is negatively associated with adaptation, with a coefficient of -0.604 significant at the 5% level. Households engaged in off-farm work are less likely to adopt adaptation practices. The justification for this result lies in the trade-offs inherent in livelihood diversification. While off-farm employment provides additional income that could theoretically support adaptation investments, it may also divert labor, time, and attention away from agriculture. As a result, households may prioritize non-farm activities over investments in farming adaptation. This finding resonates with studies from Ali (2021) where off-farm income was found to reduce engagement in farm-level adaptation strategies. On the other hand, some research has reported the opposite effect, arguing that off-farm income can strengthen adaptation by alleviating liquidity constraints.

In summary, the significant determinants of climate change adaptation among farming households are education, farming experience, household size, land tenure, group membership, and off-farm work. Education, land tenure, and group

membership facilitate adaptation, while experience, larger households, and off-farm employment constrain it. These findings highlight the complex and context-specific nature of adaptation behavior, where enabling and constraining factors coexist. Comparisons with international literature reveal both consistencies and divergences, underscoring the importance of contextual analysis. The results have critical policy implications: strengthening education, securing land tenure, and supporting farmer groups are crucial for promoting adaptation, while targeted interventions are needed to address the barriers posed by entrenched farming experience, household resource constraints, and competing off-farm employment.

3.3 Impact Climate Change Adaptation on Food Security

The empirical analysis of the impact of climate change adaptation on food security, measured through the Food Consumption Score (FCS), produces robust and consistent results across all four matching methods. In general terms, adaptation has a positive and statistically significant effect on household food security. All Average Treatment Effects on the Treated (ATT) are positive and significant at the 1% level, with estimated values ranging from 6.85 to 8.42 points depending on the method applied. This indicates that adopting households enjoy a clear advantage in terms of dietary diversity and quality when compared to non-adopters.

Table 3
Impact Climate Change Adaptation on Food Security; FCS

Matching Methode	Treatment	Control	ATT	t
Nearest Neighbor Matching	98	36	6.852	5.317***
Radius Matching	97	82	8.417	8.328***
Kernel Matching	98	82	7.908	4.201***
Stratification	98	82	7.527	4.315***

Noted: *** significant at α 1%

Looking more closely at the individual matching methods, the Nearest Neighbor Matching results show an ATT of 6.852 with a t-value of 5.317. This means that households practicing adaptation scored almost seven points higher in their FCS than comparable non-adopters. Radius Matching produced the largest effect, with an ATT of 8.417 and a t-value of 8.328, showing that stricter matching criteria yield an even stronger estimated impact of adaptation on food security. Kernel Matching confirmed the robustness of these results, with an ATT of 7.908 and a t-value of 4.201, suggesting that even when broader comparison groups are used, adaptation maintains its positive contribution. Finally, Stratification Matching reported an ATT of 7.527 with a t-value of 4.315, reinforcing the consistency of the effect across households segmented by their propensity scores. Together, these results clearly show that irrespective of the matching algorithm, adaptation substantially improves FCS outcomes.

The broader discussion of these findings centers on why adaptation practices produce such marked improvements in dietary diversity and quality. Adaptation strategies like crop diversification, improved irrigation, and soil fertility management increase production stability and reduce vulnerability to climate shocks (Ali, 2021). This translates directly into greater food availability and the ability to consume a more varied diet. The high ATT values observed, particularly in Radius Matching, suggest that households often adopt multiple complementary strategies, which together amplify the nutritional benefits. By contrast, non-adopting households are more likely to experience production shortfalls or rely on a narrower range of food items.

In the academic literature, similar patterns are widely reported. Studies from Thompson et al. (2010) demonstrate that adaptation measures contribute to higher dietary diversity and food quality. Research in africa (Asfaw et al., 2019) also found that adaptation strategies significantly raise household food security indicators. However, debates remain in the scholarly community. Some argue that the nutritional benefits of adaptation are modest, as they primarily improve production but not necessarily address food access or affordability (Tirado, Cohen et al., 2010). Others emphasize that the impact of adaptation is highly context-specific, depending on institutional support, market access, and the degree of household diversification.

In this research context, the findings suggest that adaptation does more than stabilize yields; it also facilitates access to a wider range of foods, thereby raising FCS scores. The positive and significant results across all methods also highlight the role of supportive institutions such as farmer groups and extension services, which help disseminate adaptation practices and ensure their effectiveness. This aligns with comparative evidence from regions where strong institutional engagement has magnified the benefits of adaptation for food security (Tirado, Cohen et al., 2010).

Taken together, the consistent positive effects across Nearest Neighbor, Radius, Kernel, and Stratification matching methods confirm the robustness of the relationship between adaptation and improved FCS. The magnitude of the effects between seven and eight points is non-trivial, indicating meaningful improvements in household dietary diversity and nutritional quality (Neelakantan et al., 2020). This reinforces the argument that adaptation should not only be promoted as a climate resilience strategy but also as a pathway to improved household nutrition.

From a academic perspective, these results add to the growing body of literature affirming the food security benefits of adaptation, while also highlighting ongoing debates about the limits of such benefits. While adaptation clearly raises FCS, experiential aspects of food insecurity, such as anxiety over future access or affordability, may require additional policy attention. Nonetheless, in the Indonesian setting, the evidence is clear that adaptation delivers significant nutritional gains.

This underscores the importance of scaling up adaptation strategies through education, institutional support, and policy interventions that can extend their reach and ensure that the benefits are realized across diverse farming communities. After discussing the impact of climate change adaptation on food security using FCS, we will provide further evidence using FIES indicators as evidence of multi-dimensional and multi-indicator measurement.

Table 4
Impact Climate Change Adaptation on Food Security; FIES

Matching Methode	Treatment	Control	ATT	t
Nearest Neighbor Matching	98	36	-1.939	-3.238***
Radius Matching	97	82	-2.103	-4.430***
Kernel Matching	98	82	-7.908	-4.201***
Stratification	98	82	-7.527	-4.315***

Noted: *** significant at α 1%

The empirical analysis of climate change adaptation's impact on food security, measured using the Food Insecurity Experience Scale (FIES), presents a set of consistent results across the four matching methods applied. Each method shows that adaptation is associated with a negative and statistically significant Average Treatment Effect on the Treated (ATT), meaning that adopting households experienced fewer instances of food insecurity compared to non-adopters. The Nearest Neighbor Matching approach yielded an ATT of -1.939 with a t-value of -3.238, indicating a modest but significant reduction of nearly two points in food insecurity experiences. Radius Matching produced a slightly larger effect, with an ATT of -2.103 and a t-value of -4.430, suggesting that adaptation reduced food insecurity experiences by just over two points under stricter matching criteria. Kernel Matching demonstrated the most substantial effect, with an ATT of -7.908 and a t-value of -4.201, highlighting a reduction of nearly eight points in food insecurity experiences. Finally, Stratification Matching reported an ATT of -7.527 with a t-value of -4.315, again showing a significant reduction in insecurity experiences of more than seven points. Collectively, these results confirm that adaptation consistently reduces the experiential dimensions of food insecurity, although the magnitude of the effect varies by method.

The discussion of these findings underscores the mechanisms through which adaptation alleviates food insecurity experiences. Adaptation strategies such as crop diversification, improved irrigation, and soil fertility management stabilize production and reduce the likelihood of sudden yield losses. This reliability in agricultural output lessens the frequency of anxiety and stress associated with uncertain food access, which FIES captures directly. The smaller magnitudes observed under Nearest Neighbor and Radius Matching reflect moderate improvements, while the larger reductions observed in Kernel and Stratification Matching suggest that when a broader set of households are considered, adaptation can exert profound effects. The justification for these differences may lie in the way adaptation interacts with institutional and social contexts: households supported by farmer groups, extension services, and access to local markets may realize greater benefits from adaptation, thereby reporting fewer insecurity experiences.

From a comparative perspective, the findings align with studies from Ethiopia and Kenya that have shown adaptation reduces food insecurity experiences, as households adopting climate-resilient practices report fewer instances of shortage and anxiety. Research from Ahmed, (2024) and Rahman et al. (2022) has similarly emphasized that adaptation, particularly when combined with supportive policies such as access to credit and extension services, contributes to meaningful reductions in food insecurity. However, academic debate remains. Some reserach argue that adaptation's impacts on food insecurity are constrained by structural challenges like persistent poverty, high food prices, and weak infrastructure (Brooks & Loevinsohn, 2011; Richardson et al., 2018). In these contexts, even if adaptation stabilizes yields, households may continue to face difficulties in translating production gains into secure food access. This debate highlights that adaptation is necessary but not sufficient for comprehensive food security; broader systemic interventions are also required.

Overall, the evidence from FIES analysis complements the earlier findings on the Food Consumption Score (FCS). While FCS demonstrated that adaptation enhances dietary diversity and nutritional quality, the FIES results confirm that adaptation also reduces households' lived experiences of insecurity. This dual evidence provides a more holistic understanding of adaptation's role in food security: it improves both the objective outcomes of diet and the subjective experiences of sufficiency and stability. In conclusion, adaptation emerges as a critical mechanism for improving resilience, though its full potential must be realized through integration with wider development and policy measures that address systemic vulnerabilities.

4. Conclusion

This study set out to examine the determinants of climate change adaptation among farming households and to assess its impact on household food security in the context of East Java, Indonesia. Using household survey data collected through a multi-stage sampling procedure, the analysis applied a Probit model to identify the socio-economic, demographic, and institutional factors influencing adaptation decisions, and employed Propensity Score Matching (PSM) to estimate the causal impact of adaptation on two key indicators of food security: the Food Consumption Score (FCS) and the Food Insecurity Experience Scale (FIES). The results reveal several important insights. Education, secure land tenure, and farmer group membership emerged as strong enabling factors that increased the probability of adaptation, while greater farming experience, larger household size, and engagement in off-farm employment constrained adaptation decisions. These findings suggest that human capital, institutional participation, and secure property rights play a pivotal role in facilitating adaptive responses, while

entrenched traditional practices, resource competition within households, and competing livelihood priorities limit their adoption. In terms of outcomes, the PSM analysis consistently showed that adaptation has a significant and positive effect on FCS, improving dietary diversity and nutritional quality by an average of 7–8 points across different matching methods. At the same time, adaptation was also found to significantly reduce experiential food insecurity as measured by FIES, with adopting households reporting substantially fewer instances of anxiety, compromise, or insufficiency in food access. Taken together, these findings underscore that adaptation not only improves objective consumption outcomes but also alleviates subjective experiences of insecurity, thereby contributing to a more holistic understanding of food security. Practically, this research highlights the need for policies that expand educational opportunities, strengthen farmer groups, and promote land tenure security as pathways to enhance adaptive capacity, while also addressing structural constraints such as limited credit access and the trade-offs of off-farm employment. The study contributes to the broader body of knowledge by offering context-specific evidence from Indonesia that both confirms and challenges existing theories, demonstrating that adaptation is shaped by complex socio-economic interactions and yields multifaceted benefits for household food security. In doing so, it enriches the academic debate on the role of adaptation in rural resilience and provides evidence-based guidance for policy design. Future research could build on these insights by examining the long-term sustainability of adaptation practices, exploring their interactions with market dynamics and institutional frameworks, and investigating their impacts on other dimensions of household welfare such as income stability, health, and gender equity. Ultimately, the findings reaffirm the significance of climate change adaptation as both a survival strategy for farming households and a vital policy instrument for strengthening food security in vulnerable agrarian contexts.

Author Contribution

Ketut Wira Purbawan designed the research, collected and analyzed the data, and drafted the manuscript; Nuhfil Hanani AR provided conceptual guidance and supervised the research framework; Moh Khusaini contributed to data interpretation and methodological refinement.; Anthon Efani reviewed and edited the manuscript for academic quality and clarity.

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