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Strengthening Regional Food Security in East Java Through Agricultural Innovation: Evidence From a Dynamic Panel Analysis

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Abstract

This study examines how agricultural innovation contributes to regional food security in East Java, Indonesia, which is recognised as a National Food Barn. Using district level panel data from 38 regencies and municipalities covering the years 2015 to 2023, the analysis quantifies the effects of agricultural research and development (R&D) expenditure and the number of agricultural researchers on food security outcomes. Two complementary econometric approaches, namely bootstrapped Least Squares Dummy Variable estimation and the two step System Generalized Method of Moments, are applied to address unobserved heterogeneity and endogeneity. The results show that agricultural innovation significantly improves food security. An increase of one full time equivalent agricultural researcher raises average caloric consumption by 3.5 percent and reduces the prevalence of undernourishment by 2.8 percentage points. Similarly, higher agricultural R&D expenditure increases caloric adequacy by 2.0 percent and decreases child undernourishment by 1.8 percentage points. These findings confirm that investment in human capital within agricultural research produces stronger and more consistent effects than financial inputs alone. Policy implications suggest that strengthening local research capacity and maintaining R&D funding are essential for translating innovation into measurable improvements in food access and nutrition. Replicating successful initiatives across East Java's 38 districts requires the establishment of district level agricultural innovation clusters that connect universities, research institutions, and farmer groups to accelerate technology dissemination.

Introduction

Despite its national contribution as the largest rice producing region, East Java's per capita caloric consumption in 2023 was only 2,046 kilocalories per day, which remains below the national minimum requirement of 2,100 kilocalories (BPS, 2023). This paradox shows that although East Java provides about 17.44 percent of Indonesia's rice supply, its population still faces limited food access and persistent nutritional deficiencies. Recent studies classify the province as highly vulnerable to food insecurity due to population pressure, unequal income distribution, and exposure to climate risks (Juliannisa et al., 2025). Supporting data confirm these challenges: the provincial health department reports a stunting rate of 9.56 percent among children under five and around 5 percent of households without access to clean water.

These conditions indicate that the region's food system performance depends not only on agricultural production but also on its ability to generate and apply innovations that enhance food availability and utilisation. Yet district level innovation remains underexplored using dynamic panel data, particularly in Indonesia's key food producing regions. This study addresses this gap by examining whether public investment in agricultural innovation, represented by agricultural research and development expenditure and the number of agricultural researchers, contributes to improving food security across 38 districts and municipalities in East Java.

Recent studies have classified East Java as highly vulnerable to food insecurity, primarily due to high population density, unequal income distribution, and exposure to climate risks (Juliannisa et al., 2025). Supporting data highlight these concerns: the provincial health department reports a stunting rate of 9.56% among children under five and 4.98% of households lacking access to clean water. Moreover, the National Food Agency (Badan Pangan Nasional, 2023a) reports that the province's average Normative Production Consumption Ratio is 2.74, significantly above 1, indicating a food deficit. In this context, a food deficit signifies that food availability falls short of meeting the standard consumption requirements of the population.

Among East Java's 38 regencies and municipalities, three regencies, Bondowoso, Probolinggo, and Bangkalan, fall into category 5 of the Food Security Index (IKP < 75.69), suggesting that while food security in these regions is relatively adequate, further optimization is needed. Only one regency, Gresik, scores above 90 on the composite index. Although many regions report scores above 80, the high index values are largely driven by availability, not by accessibility or utilization. These latter dimensions still offer significant room for improvement.

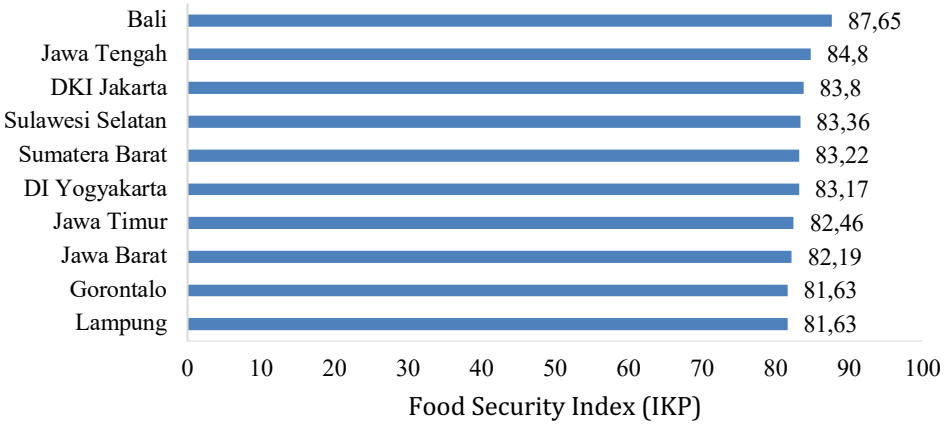
Table 1. Top 10 Regencies/Municipalities in East Java by Food Security Index (2023)

No.	Regency/Municipality	Availability	Accessibility	Utilization	Composite
1	Kabupaten Gresik	91.27	84.21	94.37	90.39
2	Kabupaten Ponorogo	95.65	83.93	85.09	87.91
3	Kabupaten Lamongan	96.98	81.11	84.65	87.28
4	Kabupaten Magetan	94.92	81.61	84.67	86.83
5	Kabupaten Mojokerto	90.91	82.82	86.44	86.70
6	Kabupaten Blitar	88.53	86.52	84.38	86.27
7	Kabupaten Bojonegoro	96.14	80.53	81.01	85.40
8	Kabupaten Madiun	95.34	83.23	79.37	85.32
9	Kabupaten Tulungagung	90.19	85.87	81.04	85.23
10	Kabupaten Ngawi	98.26	78.12	80.16	84.98

Source: Badan Pangan Nasional (2023a)

Districts with more than 60 full time equivalent agricultural researchers, such as Gresik, record Food Security Index (IKP) scores above 90, indicating that regions with stronger research capacity tend to achieve higher food security performance. This pattern suggests that local innovation potential may play an important role in enhancing district level food resilience. At the provincial level, East Java ranks only seventh in Indonesia's Food Security Index, behind Bali and Jakarta, provinces not classified as National Food Barns. This contrast further highlights the underutilized potential in East Java's food systems.

Figure 1. Top 10 Provinces by Food Security Index (IKP), 2023



Source: Badan Pangan Nasional (2023b)

Scholars and policymakers increasingly emphasise the role of agricultural innovation in strengthening food security. Numerous empirical studies confirm that public investment in agricultural research and development (R&D) enhances food security through improved productivity (Fan and Pandya Lorch, 2012; Pingali, 2012; Thirtle et al., 2003a). Kristkova et al. (2017) demonstrated that doubling global agricultural R&D expenditure can slow food price inflation and raise energy intake, while Lachaud and Bravo Ureta (2022) found that each additional dollar invested in agri-food research in Latin America yields substantial returns through productivity and nutritional improvements.

National studies abound, but evidence from district level panels covering the 2015 to 2023 period remains limited, and the use of dynamic methods such as the System Generalized Method of Moments (System GMM) has yet to be applied in this regional context. Malec et al. (2023) is one of the few exceptions; using a dynamic panel approach, they found that R&D spending and researcher capacity increase caloric adequacy and food utilisation in sub-Saharan Africa. Their results highlight the importance of innovation inputs as well as the enabling institutions that disseminate research outcomes.

This study addresses both empirical and methodological gaps by focusing on the case of East Java Province. Specifically, it examines whether public investment in agricultural innovation, represented by district level R&D expenditure and the number of agricultural researchers, contributes to improved food security across 38 districts and municipalities from 2015 to 2023. The key outcome variable is the Average Dietary Energy Requirement (ADER), an internationally recognised indicator comparing actual per-capita caloric intake with minimum physiological needs.

To estimate the dynamic relationship between innovation and food security, this study employs two econometric approaches. The first uses the Least Squares Dummy Variable estimator with bootstrapped standard errors to control for unobserved fixed effects. The second applies the two step System GMM estimator to address potential endogeneity, serial correlation, and dynamic persistence in food security outcomes. This combination ensures credible inference regarding the causal impact of innovation on nutrition and food access.

This research makes five key contributions. First, it provides the first district level panel analysis in Indonesia linking agricultural innovation to food security outcomes. Second, it introduces internationally comparable metrics such as ADER into subnational policy assessment. Third, it employs dynamic panel methods to generate robust causal evidence. Fourth, by focusing on East Java, a province of strategic agricultural significance, it produces insights relevant to other regions facing similar structural challenges. Fifth, it provides a practical blueprint for allocating agricultural researchers across districts to achieve an ADER level exceeding 2 100 kilocalories per capita per day. The remainder of this article is organised as follows: Section 2 reviews the theoretical framework and related literature; Section 3 describes the data and methodology; Section 4 presents and discusses the results; and Section 5 concludes with policy implications and recommendations for future research

Methods

3.1 Research Design

This study adopts a quantitative research design using a panel data framework to examine the impact of agricultural innovation investment on food security across 38 districts and municipalities in East Java, Indonesia, during the period 2015 to 2023. The selection of East Java is based on its strategic role as a national agricultural centre and its substantial variation across districts in food security outcomes, innovation capacity, and agricultural productivity. The panel data approach is appropriate for this investigation because it allows control for unobserved heterogeneity, captures temporal dynamics, and improves the precision and consistency of coefficient estimates (Baltagi, 2008). This design is commonly

applied in development and agricultural economics to assess policy impacts in decentralised and heterogeneous settings (Arellano and Bover, 1995; Judson and Owen, 1999).

In line with recent empirical works such as Malec et al. (2023) and Fuglie and Rada (2013), which examine the effects of agricultural innovation on food security in sub-Saharan Africa, this study integrates both static and dynamic estimation techniques to validate the robustness of the results. The static model is estimated using the Least Squares Dummy Variable method, which controls for fixed effects across districts and time to account for structural regional differences. To address the potential endogeneity of innovation inputs and reverse causality, where better food security conditions may attract more research and development investment, the System Generalized Method of Moments approach (Blundell and Bond, 1998) is employed. This estimator is particularly suitable for relatively short panel data with possible autocorrelation, measurement errors, and endogenous regressors.

The dual application of the Least Squares Dummy Variable and System Generalized Method of Moments techniques provides a comprehensive and credible analysis of how public agricultural investment and researcher capacity influence regional food security. This methodological combination follows best practices in innovation and food security research, where dynamic relationships and policy lags are essential considerations (Roodman, 2009). The study relies entirely on publicly available secondary data obtained from Statistics Indonesia (Badan Pusat Statistik, BPS) and district level government financial reports. As all datasets are aggregated and anonymised, no personal information or individual consent was required.

3.2 Data and Variable Operationalization

Following relevant literature in food security and agricultural innovation, this study uses two primary indicators of food security: the average daily caloric intake per capita and the prevalence of undernourished children. These indicators serve as proxies for food availability and nutritional utilisation at the district level. The caloric intake indicator measures the energy supply available to an average individual, standardised by recommended daily energy requirements, while the prevalence of undernourished children reflects chronic food inadequacy among vulnerable groups. Data for both indicators are obtained from Indonesia's National Socioeconomic Survey (SUSENAS), the Basic Health Survey (Riskesdas), and the Food Security and Vulnerability Atlas (FSVA). Since these two indicators capture different dimensions of food security, each was used as a separate dependent variable in the estimations to ensure clarity and comparability across models.

Agricultural innovation is measured using two commonly accepted proxies: the number of agricultural researchers (AR), expressed in full time equivalents, and public agricultural research and development (R&D) expenditure (RD) sourced from local government budgets. The number of researchers represents the region's innovation capacity and human capital in agricultural research, while R&D expenditure reflects the institutional and financial commitment to advancing agricultural technology (Fuglie & Rada, 2013; Malec et al., 2023). Data on researchers are drawn from the annual reports of BRIN's Assessment and Development Centres for Agricultural Technology (Balai Pengkajian Teknologi Pertanian, BPTP) and the Science and Technology Index (SINTA) database under the Ministry of Education, Culture, Research and Technology (Kemdikbudristek). R&D

expenditure data are obtained from local government budget documents and the national procurement database (SIRUP–LKPP).

Several control variables are included in the model. Food production per capita (FPC) captures regional food availability, measured as the total output of staple crops divided by population. The food price index (FPI) represents food affordability, as changes in prices affect household access to adequate calories. Population growth rate (PG) is incorporated to account for demographic pressure, since a larger population increases demand on food systems and distributional efficiency (Boliko, 2019; Lachaud and Bravo Ureta, 2021). All variables are measured annually and compiled into an unbalanced panel dataset due to missing observations. The dataset covers 38 districts and municipalities in East Java from 2015 to 2023. Table 2 below presents a summary of the variable definitions, proxies, and data sources.

Table 2. Data and Variable Operationalization

No	Variable (Code)	Operational Definition	Unit of Measure	Indicator / Proxy	Data Source
1	Food Security (FS)	Adequacy of energy and nutrient consumption reflecting food availability and utilization	Percent (%) / Score	a) Caloric consumption per capita per day b) Prevalence of undernourished children	SUSENAS – BPS: Riskesdas – Litbangkes: FSVA – BKP
2	Agricultural Researchers (AR)	Number of active agricultural researchers (FTE) in the region	Persons (FTE)	Researchers in BPTP, local research agencies, and universities	BRIN – BPTP SINTA – Kemdikbud
3	Agricultural R&D Expenditure (RD)	Total public budget for agricultural R&D at local level	Million IDR	Annual agricultural R&D expenditure on district APBDs	SIRUP – LKPP DPKP
5	Food Production per Capita (FPC)	Total production of major food crops divided by population	Kg/capita	Total output of rice, maize, soybean ÷ district population	BPS

No	Variable (Code)	Operational Definition	Unit of Measure	Indicator / Proxy	Data Source
6	Food Price Index (FPI)	Index measuring changes in food prices, indicating affordability	Index (Base Year = 2018)	CPI for food groups in major East Java cities	BPS
7	Population Growth Rate (PG)	Annual percentage growth in population	Percent (%)	((Population$_t$ – Population$_{t-1}$) / Population$_{t-1}$) × 100	BPS

Source: Author's processed (2025)

3.3 Model Specification

To examine whether investments in agricultural innovation improve food security in East Java, this study adopts an empirical modelling strategy grounded in the food security framework developed by Warr (2005), which posits that food security is primarily determined by food availability and food affordability. In the baseline specification, food production per capita (FPC) serves as a proxy for food availability, while the food price index (FPI) represents food affordability. The static panel model is specified as follows:

$$FS_{it} = \rho_0 + \rho_1 FPI_{it} + \rho_2 FPC_{it} + \varepsilon_{it} \quad (1)$$

where FS_{it} denotes food security in district i at year t; FPI_{it} is the food price index; FPC_{it} is food production per capita; and ε_{it} is the error term. This model is then extended to include key innovation variables and demographic controls. Specifically, we include the number of agricultural researchers (AR_{it}), and agricultural R&D expenditure (RD_{it}). The extended static models are written as:

$$FS_{it} = \rho_0 + \rho_1 FPI_{it} + \rho_2 FPC_{it} + \rho_3 PG_{it} + \rho_4 AR_{it} + \rho_5 RD_{it} + \vartheta_i + \tau_t + \varepsilon_{it} \quad (2)$$

where ϑ_i and τ_t are district and time fixed effects, respectively; PG_{it} is is the annual population growth rate; AR_{it} is the number of agricultural researchers (FTE); and RD_{it} is agricultural R&D expenditure at the district level. This unified model allows the simultaneous estimation of both human and financial innovation inputs, providing a more comprehensive assessment of how agricultural research capacity and expenditure jointly influence food security outcomes across districts. The model is estimated using the Least Squares Dummy Variable (LSDV) approach with bootstrapped standard errors to account for unobserved heterogeneity and enhance robustness of the coefficient estimates.

To address potential endogeneity and dynamic relationships, we implement the two-step System Generalized Method of Moments (System GMM) estimator, developed by Arellano & Bover (1995) and Blundell & Bond (1998). This approach is particularly suitable for panels with many cross-sectional units and relatively short time spans. The dynamic specification includes a lag of the dependent variable to capture temporal persistence in food security outcomes:

$$FS_{it} = \gamma_0 + \gamma_1 FS_{it-1} + \gamma_2 AR_{it} + \gamma_3 RD_{it} + \gamma_4 FPI_{it} + \gamma_5 FPC_{it} + \gamma_4 PG_{it} + \vartheta_i + \tau_t + \varepsilon_{it} \quad (3)$$

All System GMM estimations are conducted using two-step procedures with robust standard errors corrected by the Windmeijer (2005) finite-sample adjustment. The validity of the instruments is tested through the Hansen J-test for overidentifying restrictions, while the Arellano–Bond tests for AR(1) and AR(2) are employed to ensure there is no serial correlation in the differenced residuals. This model specification strategy allows for the identification of both direct and indirect effects of agricultural innovation on food security, while accounting for endogeneity, measurement errors, and unobserved heterogeneity across districts.

Result

Table 3 summarises the descriptive statistics of the variables across 38 districts in East Java from 2015 to 2023. The mean food security index (FS) is 79.00 percent, indicating a generally moderate level of nutritional adequacy and food availability in the region. The average number of agricultural researchers (AR) is approximately 49.93 full time equivalents, while the mean agricultural research and development expenditure (RD) reaches around IDR 9.9 billion per district per year, suggesting notable variation in local investment in agricultural innovation. Food production per capita (FPC) averages 257.21 kilograms, indicating a relatively sufficient supply to meet local consumption needs. The food price index (FPI) averages 110.75, suggesting moderate inflation in food prices, while the average population growth rate (PG) remains stable at 1.17 percent annually.

Table 3. Descriptive Statistics

Variables	Mean	Std. Dev.	Min	Max
FS	79.0	4.79	70.2	89.26
AR	49.93	14.4	10.7	73.47
RD	9868.35	1786.25	6024.86	14926.48
FPC	257.21	47.71	174.26	386.01
FPI	110.75	5.46	100.66	129.26
PG	1.17	0.34	0.23	1.84

Source: Author's processed (2025)

Table 4 presents the correlation matrix among the study variables. Most coefficients are weak to moderate, indicating a low risk of multicollinearity in the empirical model. Notably, FPI is negatively correlated with FS (−0.26), supporting the hypothesis that rising food prices undermine food security. Agricultural researchers (AR) are modestly correlated with food production (FPC = 0.23), suggesting a potential productivity enhancing role. The correlation between RD and FS is negative (−0.20), possibly reflecting time lags between R&D investment and measurable food security outcomes. This negative RD–FS correlation (−0.20) likely reflects a two-to-three-year R&D lag, consistent with empirical evidence in the literature that innovation effects materialise gradually over time (Fuglie and Rada, 2013; Kristkova et al., 2017; Lachaud and Bravo Ureta, 2022).

Table 4. Correlation Matrix

	FS	AR	RD	AP	FPC	FPI	PG
FS	1.0						
AR	-0.18	1.0					
RD	-0.2	0.03	1.0				
FPC	0.05	0.23	-0.19	-0.09	1.0		
FPI	-0.26	-0.02	-0.04	0.09	-0.16	1.0	
PG	0.2	-0.3	0.2	-0.05	0.13	-0.1	1.0

Source: Author's processed (2025)

Bootstrapped Least Squares Dummy Variable (LSDV) results in Table 5 indicate that investments in agricultural innovation significantly enhance food security by increasing average caloric consumption per capita across districts in East Java. Specifically, a one unit increase in the number of full time equivalent agricultural researchers (AR) leads to an estimated 3.5 percentage point rise in caloric intake, while a corresponding increase in agricultural research and development expenditure (RD) is associated with a 2.0 percentage point gain in caloric adequacy.

The results further show that key control variables behave as expected. Population growth (PG) exerts a significant negative influence on caloric consumption, indicating that rising demographic pressure tends to reduce per capita food availability. Conversely, food production per capita (FPC) remains a strong and positive determinant of dietary energy intake, supporting the central role of domestic food supply in meeting nutritional needs. The food price index (FPI), as anticipated, shows a negative effect, although its magnitude becomes statistically insignificant once innovation variables are included—possibly suggesting that innovation buffers the adverse effects of rising food prices.

Table 5. Bootstrapped LSDV Results on the Effects of Investments in Agricultural Innovation on Caloric Consumption per Capita per Day

Variables	Baseline Model	Agric. Researchers	Agric. R&D
PG	−0.052***	−0.046***	−0.042**
	(0.006)	(0.006)	(0.007)
FPI	−0.024**	−0.010	−0.012
	(0.012)	(0.020)	(0.019)
FPC	0.120***	0.060**	0.058**
	(0.027)	(0.030)	(0.028)
AR		0.035***	
		(0.005)	
RD			0.020***
			(0.004)
District FE	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes
Observations	438	343	343
R-squared	0.373	0.550	0.535
Bootstrap Replication	50	35	35

*, ** , *** represent significance at 10%, 5%, and 1% levels, respectively.

Table 6 reports the bootstrapped LSDV results assessing the effects of agricultural innovation on the prevalence of undernourished children across East Java's districts. The results demonstrate that both proxies of innovation, agricultural researchers (AR) and R&D expenditure (RD), are significantly associated with reductions in child undernourishment. Specifically, an increase in AR reduces undernourishment prevalence by approximately 2.8 percentage points, while a rise in RD yields a 1.8 percentage point decline. These findings affirm that investment in agricultural innovation plays a critical role in improving nutritional outcomes among vulnerable populations. Consistent with theoretical expectations, food production per capita (FPC) is negatively and significantly related to undernourishment, indicating that improved food availability contributes directly to child nutrition. Conversely, population growth (PG) and food price inflation (FPI) exert positive effects, suggesting that demographic pressures and reduced affordability pose risks to child food security.

Table 6. Bootstrapped LSDV Results on the Effects of Investments in Agricultural Innovation on the Prevalence of Undernourished Children

Variables	Baseline Model	Agric. Researchers	Agric. R&D
PG	0.045***	0.040***	0.038***
	(0.009)	(0.008)	(0.009)
FPI	0.022*	0.015	0.016
	(0.013)	(0.014)	(0.015)
FPC	−0.110***	−0.085**	−0.080**
	(0.030)	(0.032)	(0.031)
AR		−0.028**	
		(0.008)	
RD			−0.018**
			(0.007)
District FE	Yes	Yes	Yes
Time Dummies	Yes	Yes	Yes
Observations	396	326	326
R-squared	0.360	0.495	0.480
Bootstrap Replication	50	22	21

*, ** , *** represent significance at 10%, 5%, and 1% levels, respectively.

The two-step System GMM results in Table 7 corroborate the prior findings from LSDV estimations, indicating that investments in agricultural innovation significantly influence food security in East Java. Specifically, both the number of agricultural researchers (AR) and agricultural R&D expenditure (RD) demonstrate positive and statistically significant effects on caloric consumption per capita per day. The AR variable increases caloric intake by approximately 4.5 percentage points, while RD contributes an increase of 3.2 percentage points. These results suggest that innovation inputs, such as human capital and financial investment in research, effectively enhance the availability and utilization of food at the household level.

Turning to the models for undernourishment prevalence, both innovation variables also yield negative and statistically significant coefficients, supporting the hypothesis that innovation investments reduce food insecurity. The effect of AR is particularly notable,

reducing the prevalence of undernourished children by approximately 5.7 percentage points, although at the 5% level of significance. RD, in contrast, reduces undernourishment by about 7.5 percentage points and is weakly significant at the 10% level. These findings align with previous literature (e.g., Mughal & Sers, 2022; Malec et al., 2024) which show that agricultural innovation plays a crucial role in alleviating food insecurity.

Among the control variables, population growth (PG) shows a significant negative relationship with caloric intake in the RD model and with undernourishment in both AR and RD models. This implies that a higher rate of population growth exerts pressure on food systems, potentially increasing the risk of food insecurity unless mitigated by technological progress or innovation. The food price index (FPI) exhibits a marginal negative effect on caloric intake but is not significant in explaining undernourishment, indicating that affordability has a more limited short-term impact in this regional context. Meanwhile, food production per capita (FPC) shows a positive and weakly significant association with caloric intake, while unexpectedly yielding a negative coefficient for undernourishment in the AR model, suggesting complex dynamics between production, distribution, and nutritional outcomes.

Model validation tests indicate robust estimation results. The Hansen J-statistics across all models yield p-values above the common significance thresholds, confirming the validity of the instruments. Similarly, the Arellano-Bond test for second-order serial correlation (AR(2)) yields non-significant p-values in all models, suggesting no autocorrelation in the differenced residuals. The F-statistics are consistently large, indicating high joint significance of the explanatory variables.

Table 7. Two-Step System GMM Results on the Effects of Investments in Agricultural Innovation on Caloric Consumption per Capita per Day and the Prevalence of Undernourished Children

Variables	Caloric Consumption per Capita per Day			Prevalence of Undernourished Children		
	Baseline Models	Agric. Res. (AR)	Agric. R&D (RD)	Baseline Models	Agric. Res. (AR)	Agric. R&D (RD)
Lagged Dep. Var. $_{(t-1)}$	1.210***	1.005***	0.690***	−0.244***	0.711**	1.219***
	(0.290)	(0.260)	(0.105)	(0.057)	(0.354)	(0.098)
PG	0.012	−0.022	−0.045*	−0.037	−0.028	−0.181**
	(0.035)	(0.038)	(0.027)	(0.035)	(0.160)	(0.083)
FPI	−0.028*	−0.030*	0.005	0.136	0.183	0.090
	(0.016)	(0.017)	(0.015)	(0.092)	(0.129)	(0.077)
FPC	0.085	0.140*	0.098	0.089	−0.964**	0.161
	(0.065)	(0.076)	(0.081)	(0.080)	(0.394)	(0.219)
AR		0.045**			−0.057**	
		(0.020)			(0.304)	
RD			0.032**			−0.075*
			(0.014)			(0.042)
Observations	414	319	295	374	319	298
Instruments Used / Available	24/38	21/38	20/38	24/38	21/38	20/38
Hansen p-value	0.312	0.301	0.462	0.341	0.210	0.483
AR(2) p-value	0.295	0.180	0.120	0.643	0.172	0.113
F-Statistics	120456.12	89043.25	150234.88	109089	92043	178960.80

*, ** , *** represent significance at 10%, 5%, and 1% levels, respectively.

Notably, AR variables appear to exert larger impacts on both caloric intake and undernourishment reduction compared to RD. This may be attributed to the more direct and immediate influence of researchers' fieldwork and adaptive solutions in localized contexts, especially in regions with diverse agroecological conditions like East Java. As emphasized in previous studies (Fuglie & Rada, 2013; Malec et al., 2024), human capital in the form of agricultural researchers often proves more flexible and responsive than budgetary inputs, which may be delayed or misallocated. Researchers are also more likely to engage with stakeholders, identify context-specific challenges, and apply research outcomes in ways that directly address local food security concerns.

Discussion

This study provides robust empirical evidence that agricultural innovation significantly improves food security outcomes in East Java, Indonesia. Both the static LSDV and dynamic System GMM models consistently demonstrate that investments in innovation, proxied by the number of agricultural researchers and agricultural R&D spending, are positively associated with increased per capita caloric consumption and reduced prevalence of undernourishment. The consistent statistical significance of both variables across models suggests that innovation plays a critical role in enhancing the availability and utilization dimensions of food security.

In particular, the variable capturing the number of agricultural researchers exhibits strong and consistent effects, underscoring the importance of human capital in the research and innovation system. This finding aligns with Malec et al. (2023), who reported that full-time equivalents of agricultural researchers had a greater impact on food security than R&D expenditures in Sub-Saharan Africa. Similarly, Fuglie & Rada (2013) documented high returns to research investments across African countries, emphasizing that underinvestment in agricultural R&D has limited productivity growth and food supply improvements. In Indonesia, this suggests the need for policies that enhance human capital in agriculture, such as the implementation of the Law on Agricultural Research and Development (Law No. 13/2019), which promotes investment in agricultural education and research funding (Rahman, 2022). These findings reaffirm the broader theoretical framework that positions innovation as a primary driver of productivity, food availability, and poverty reduction (Thirtle et al., 2003b).

The dynamic GMM results in our analysis reinforce the robustness of these relationships. The significant coefficients on lagged dependent variables indicate persistence in food security outcomes, as well as the need to account for past trends when evaluating policy impacts. Moreover, the statistical significance of innovation variables even after addressing potential endogeneity suggests a causal relationship, rather than mere correlation driven by omitted variables or reverse causality (Chen & Xing, 2025). This indicates that agricultural policies should also consider historical data and trends, potentially influencing the formulation of the National Medium-Term Development Plan (RPJMN), which prioritizes food security (Mufida, 2024). This reinforces the conclusion that investing in agricultural innovation has direct and measurable effects on food security.

Our findings also resonate with global and regional experiences. The Green Revolution, particularly in Asia and Indonesia, exemplified how agricultural innovation through high-yielding varieties and improved agronomic practices can rapidly increase food availability and reduce hunger (Pingali, 2012). The success of Indonesia's Green Revolution underscores the importance of ongoing investment in agricultural innovations, as seen in the Food Self-Sufficiency Program, which aimed to achieve and maintain rice self-sufficiency (Hulu & Rahayu, 2024; Susanti et al., 2024). In Indonesia, these innovations led to rice self-sufficiency by the 1980s and significantly reduced the prevalence of undernourishment (USDA, 2010). More recent model-based analyses, such as Kristkova et al. (2017), show that increased R&D spending globally can decelerate food price inflation and boost caloric intake, especially for vulnerable populations. In Latin America, Lachaud & Bravo-Ureta (2022) also found high internal, and spillover returns from agricultural R&D, reinforcing the economic rationale for increased innovation investments in middle-income developing countries.

The role of control variables in this study supports theoretical expectations. The food price index (FPI) has a negative and significant association with caloric consumption, indicating that higher food prices reduce access, especially for low-income populations (Bozsik et al., 2022; Dardeer & Shaheen, 2025). Conversely, food production per capita (FPC) positively influences dietary outcomes, emphasizing the importance of food availability (Warr, 2005). The effect of population growth is mixed, suggesting that demographic dynamics interact with resource availability and innovation capacity, as also discussed by Herath (1985).

East Java provides a compelling subnational case study. As a region with relatively strong infrastructure and institutional capacity, East Java appears well-positioned to convert innovation inputs into tangible food security improvements (Rajalahti, 2021). The positive results may reflect effective agricultural extension services, robust linkages between research institutions and farmers, and the availability of complementary infrastructure such as irrigation and rural roads. However, experiences from other regions caution against assuming automatic benefits from innovation spending. Malec et al. (2023) found that in Central Africa, similar investments failed to improve food security, likely due to weak institutions, conflict, and poor dissemination mechanisms. These findings underscore that innovation must be embedded in a conducive environment to achieve its intended outcomes.

A local example illustrates how targeted innovation can yield concrete benefits. In Gresik District, which has 73 full time equivalent agricultural researchers, local research teams successfully developed flood resistant rice varieties that have improved yields in waterlogged lowland areas. Replicating this model in districts with lower Food Security Index (IKP) scores, such as Bondowoso (IKP < 75), could significantly enhance food resilience by aligning innovation initiatives with district specific agroecological challenges. Such localised replication demonstrates how empirical findings can inform policy design and guide the equitable distribution of research resources across East Java.

The policy implications are clear. First, scaling up investment in agricultural R&D should be prioritized at both provincial and national levels. The significant impacts found in this study suggest that such investments yield high social returns, especially in terms of improving dietary energy supply and reducing child undernutrition (Heidkamp et al., 2021). Second, building and sustaining a skilled agricultural research workforce is critical. The strong impact of the researcher variable suggests that human capital is not easily substitutable and that funding without expertise may be ineffective (Lin et al., 2021). Third, policies should focus on enhancing the efficiency and collaboration of research institutions. Greater coordination among universities, research agencies, and the private sector can prevent duplication and accelerate innovation. International examples, including regional R&D collaborations, may offer lessons for Indonesia in amplifying innovation outcomes with limited resources (Wahrudin, 2025).

Furthermore, innovation must be coupled with effective dissemination. Strengthening extension systems, ensuring farmer access to improved technologies, and aligning innovation with local needs are essential to translating research into real-world

impact. Supporting policies such as input subsidies, rural credit schemes, and market access improvements can further enhance the adoption and effectiveness of innovations.

This study adds to the growing evidence that agricultural innovation through both financial and human capital investments significantly improves food security. The findings from East Java corroborate international experiences, affirming that innovation-driven productivity growth can simultaneously enhance food availability and access, thereby reducing undernourishment. These insights provide a strong empirical basis for policy efforts aimed at achieving Sustainable Development Goal 2 (zero hunger). Continued commitment to agricultural R&D and institutional strengthening will be essential to sustain and scale these benefits.

Conclusion

This study provides compelling empirical evidence that agricultural innovation significantly improves food security outcomes in East Java. The use of both static LSDV and dynamic System GMM estimation techniques confirms that higher levels of agricultural research and development expenditure and a greater number of agricultural researchers are positively associated with increased caloric consumption per capita and reduced prevalence of undernourishment. The consistency of results across models reinforces the causal link between innovation and food security, even after controlling for unobserved heterogeneity and endogeneity. These findings are in line with a broad body of global literature that underscores the vital role of agricultural innovation in boosting productivity, improving food availability, and lowering hunger levels. The effect of innovation is particularly pronounced when human capital is involved, as researchers play a central role in developing context specific solutions and facilitating technology adoption.

The evidence also shows that food production per capita has a positive impact on dietary outcomes, while higher food prices constrain access, reaffirming the multifaceted dimensions of food security. The success observed in East Java, a region with relatively strong infrastructure and institutional support, further illustrates the importance of enabling environments in maximising the impact of innovation. The findings imply that policymakers should prioritise scaling up investments in agricultural research and development, build and retain qualified agricultural researchers, and enhance coordination between research institutions, the private sector, and extension services. In line with President Prabowo's focus on food sovereignty, the Indonesian government could establish dedicated funding mechanisms, such as the National Research Fund, to ensure consistent financial backing for agricultural research projects. This aligns with the efforts outlined in the Food Sovereignty Law (Law No. 18 of 2012), which emphasises self sufficiency in food production. Strengthening dissemination mechanisms and ensuring that innovations reach farmers is critical to translating research into tangible improvements in food systems. Implementing robust extension services through programmes like the Agricultural Technology Transfer Programme can help bridge the gap between research outputs and farmer applications, complementing the government's ongoing initiatives to enhance agricultural productivity.

Additionally, reallocating resources from less effective programmes, such as input subsidies, toward long term productivity enhancing innovations can yield substantial returns in terms of food availability and nutritional gains. The government could conduct a comprehensive review of existing subsidy programmes under the Ministry of Agriculture as part of the National Food Security Strategy to identify inefficiencies and potential

reallocation opportunities. This strategy aims to optimise resource allocation to better support sustainable food production. Although the study offers robust insights, it also presents some limitations. The indicators used do not capture the quality or specificity of innovation outputs, and the timeframe may be too short to observe long term or lagged effects. Future research could explore more nuanced types of innovation, assess their sustainability over time, and investigate the role of institutional quality, climate resilience, and infrastructure in moderating the effectiveness of innovation on food security.

In conclusion, this study reinforces that agricultural innovation through both financial investment and human capacity is a critical lever for achieving food security. To this end, the Indonesian government should reaffirm its commitment to agricultural innovation by integrating findings from this study into the National Medium Term Development Plan (RPJMN), ensuring that agricultural development remains a policy priority. Additionally, President Prabowo's administration can leverage ongoing projects such as the Food Security and Resilience Programme, which focuses on enhancing agricultural innovation and infrastructure. Continued and well targeted support for research and innovation will be essential for East Java and other regions seeking to eradicate hunger and build resilient food systems.

To operationalise these insights, three actionable policy recommendations are proposed:

1. Establish a minimum threshold of 60 full time equivalent (FTE) agricultural researchers per district to achieve and sustain a Food Security Index (IKP) above 90, based on empirical evidence from leading districts such as Gresik.
2. Allocate at least 2 percent of total regional agricultural expenditure to research and development activities, ensuring continuous funding for adaptive innovations aligned with local agroecological conditions.
3. Mandate annual coordination platforms among district research agencies, universities, and farmer cooperatives to facilitate technology dissemination, joint field trials, and policy feedback loops across East Java's 38 districts.

These actions translate the study's findings into measurable, locally adaptable strategies that strengthen Indonesia's pathway toward food sovereignty and the achievement of Sustainable Development Goal 2 (Zero Hunger).

Declarations

No ethical issues have arisen during the study, and all procedures followed complied with applicable ethical standards.

Authors contribution statement

Hapid Durohman conceptualized the study, designed the methodology, and carried out data collection, statistical analysis, and visualization. Muhammad Yuka Anugrah was responsible for drafting the introduction section. Danial Muhammad Wirdyansyah contributed to the literature review and preparation of the manuscript draft. The interpretation of results was conducted jointly by all authors. All authors reviewed, revised, and approved the final version of the manuscript.

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Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. Data sourced from Statistics Indonesia (BPS), the National Food Agency, and regional government reports are publicly accessible through their official platforms.

Declaration of interests statement

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

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