



# The Role of Agricultural Innovation Investment in Enhancing Food Security: Evidence from Yogyakarta

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This study investigates the effect of agricultural innovation, proxied by public agricultural R&D expenditures and the number of agricultural researchers, on food security outcomes in the Special Region of Yogyakarta (DIY), Indonesia. Using a panel dataset covering five districts from 2010 to 2023, the study applies the bootstrapped Least Squares Dummy Variable (LSDV) estimator to control for unobserved district and time effects and to enhance the robustness of inference. Food security is measured by per capita caloric intake, while innovation inputs are drawn from local government and agricultural agency records. The results indicate that agricultural innovation has a statistically significant and positive impact on food security. Among the innovation variables, the number of agricultural researchers shows a more consistent and stronger association with increased dietary energy consumption than R&D spending, underscoring the importance of human capital in converting scientific advancements into tangible outcomes. The findings highlight that even in regions with modest agricultural output, such as Yogyakarta, institutional support, knowledge dissemination, and effective extension services can enhance the benefits of innovation. The study recommends increased investment in researcher capacity and improved coordination among provincial research stakeholders to achieve inclusive and sustainable food security improvements.

## OPEN ACCESS

ISSN 2985-3257 (Online)

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Received: 15 September 2025

Accepted: 7 November 2025

Published: 30 November 2025

Citation:

(2025) The Role of Agricultural Innovation Investment in Enhancing Food Security: Evidence From Yogyakarta. *Islamic Social Finance*, 5.1.

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**Keywords:** Agricultural Innovation; Food Security; R&D; Yogyakarta, Indonesia

## INTRODUCTION

Food security policies represent a strategic priority in the Special Region of Yogyakarta, even though Yogyakarta is not among the six provinces designated as a National Food Barn (Lumbung Pangan Nasional). Unlike East Java – which is the largest rice producer in Indonesia – Yogyakarta’s agricultural output is relatively modest. According to Indonesia’s Central Bureau of Statistics (BPS, 2025), Yogyakarta’s rice production in 2024 was estimated at only 454.27 thousand tons of milled dry grain, roughly 1% of the national rice supply. The province is not a major contributor to staple commodities like rice or maize at the national level. Nevertheless, ensuring food security for its population remains a critical concern for the region.

Paradoxically, despite its smaller role in national food production, Yogyakarta still faces significant challenges in meeting the nutritional needs of its own residents. The province’s rice output has shown signs of strain, declining by about 14.95% from 2023 to 2024. More importantly, the average per capita dietary energy consumption in Yogyakarta was only 2,053 kcal/day in 2023, which falls below the national minimum requirement of 2,100 kcal/day (BPS, 2023). This indicates that, on average, residents’ food intake has not yet met minimum nutritional standards, mirroring the food intake gap observed in other regions.

Recent studies have classified Yogyakarta as vulnerable to food insecurity due to a combination of high population density, unequal income distribution, and localized climate risks (Juliannisa et al., 2025). Supporting data highlight these concerns. The provincial

health survey reports that the stunting prevalence among children under five in Yogyakarta rose to 18.0% in 2023, up from 16.4% in 2022. This rate exceeds the national target (14% by 2024) and approaches the WHO threshold for public health concern (20%), signaling persistent malnutrition issues. Access to clean water and sanitation, while generally high, is not yet universal – only about 78.9% of households have access to basic hygienic facilities indicating that a portion of the population still lacks adequate water security. Moreover, the National Food Agency (Badan Pangan Nasional, 2023a) notes that Yogyakarta’s Normative Consumption-to-Production Ratio exceeds 1, implying a food deficit situation. In this context, a food deficit means that local food availability does not meet the standard consumption needs of the population, necessitating reliance on imports from other regions.

Among the five regencies and municipalities in Special Region of Yogyakarta, composite Food Security Index (IKP) scores generally indicate adequate food security, with all regions scoring above 80. Kulon Progo leads with a composite score of 85.54, followed by Sleman and Yogyakarta City. However, a closer examination of the sub-dimensions reveals structural imbalances. Gunungkidul reports the highest availability score (98.15) but exhibits relatively weak performance in accessibility and utilization. In contrast, Sleman and Yogyakarta City demonstrate stronger outcomes in accessibility and utilization despite lower availability. These findings underscore that food security challenges in Yogyakarta are less about physical availability and more related to disparities in access and effective utilization.

**Table 1.** Five Regencies/Municipalities in Yogyakarta by Food Security Index (2023)

No.	Regency/Municipality	Availability	Accessibility	Utilization	Composite
1	Kulon Progo	89.61	78.74	87.58	85.54
2	Bantul	73.11	83.49	87.74	82.07
3	Gunung Kidul	98.15	75.04	75.05	81.98
4	Sleman	66.51	90.17	90.40	83.16
5	Yogyakarta City	-	90.29	77.24	83.11

Source: [Badan Pangan Nasional \(2023a\)](#)

At the provincial level, Yogyakarta ranks sixth nationally in the 2023 Food Security Index with a composite score of 83.17, placing it in the “food secure” category. Despite not being a designated National Food Barn, this performance reflects the province’s effective

distribution systems, social programs, and innovation. However, disparities across districts reveal persistent challenges and underutilized potential within Yogyakarta’s food system.



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

Source: [Badan Pangan Nasional \(2023b\)](#)

Food security is a multidimensional concept central to the Sustainable Development Goal 2 (Zero Hunger), aiming to prevent hunger, reduce malnutrition and underweight prevalence (Leung et al., 2014), improve mental health (Reeder et al., 2022), and reduce poverty (Malec et al., 2023). It also contributes to productivity and economic well-being (ILO, 2005), reduces food-related conflict (Brinkman & Hendrix, 2011), and promotes social stability. The attainment of national and regional food security is, therefore, intrinsically tied to household-level food security. Addressing systemic gaps—particularly traditional, unsustainable agricultural methods and population growth pressures—is critical for strengthening food systems in Yogyakarta (Raharto, 2010).

Scholars and policymakers increasingly emphasize the role of agricultural innovation in bolstering food security. Numerous empirical studies confirm that public investment in agricultural research and development (R&D) significantly improves food security through enhanced productivity (Fan & Pandya-Lorch, 2012; Pingali, 2012; Thirtle et al., 2003a). Kristkova et al. (2017), using a global computable general equilibrium model, showed that doubling global agricultural R&D spending significantly slows food price inflation and increases energy intake. Similarly, Lachaud & Bravo-Ureta (2022) report that each additional dollar invested in agri-food R&D in Latin America yields up to \$19 in returns through productivity and food security improvements.

However, most prior research focuses on national or cross-country levels. Few studies rigorously examine regional disparities, and even fewer account for

agricultural innovation as a central variable using dynamic econometric frameworks. Malec et al. (2023) is one of the few exceptions; using a dynamic panel approach (System GMM), they show that R&D spending and researcher capacity significantly increase caloric adequacy and food utilization in sub-Saharan Africa. Their findings highlight not only the importance of innovation inputs, but also the role of enabling institutions and dissemination mechanisms.

This study addresses both empirical and methodological gaps by focusing on the case of Yogyakarta Province. Specifically, it investigates whether public investments in agricultural innovation—measured by district-level R&D expenditures and the number of agricultural researchers—contribute to improved food security across 5 districts and municipalities from 2010 to 2023. The primary food security outcome variable is the Average Dietary Energy Requirement (ADER), an internationally standardized metric that compares actual per capita caloric intake with the minimum physiological requirement.

To examine the relationship between agricultural innovation and food security in Yogyakarta, this study employs the Least Squares Dummy Variable (LSDV) estimator with bootstrapped standard errors, enabling control for unobserved district-level and temporal heterogeneity while enhancing robustness through data resampling. This approach is particularly suitable given the relatively small number of districts and the short panel structure. The study offers four key contributions. First, it presents the first district-level panel data analysis in Yogyakarta investigating the nexus between agricultural innovation and food security.

Second, it integrates internationally recognized indicators, such as the Average Dietary Energy Requirement (ADER), into subnational food policy evaluation. Third, it applies a bootstrapped LSDV technique to strengthen the reliability of causal inference under data constraints. Fourth, by focusing on Yogyakarta—a province with unique socio-agricultural characteristics—the study provides context-specific insights that may inform regional policy strategies in similarly structured areas. The remainder of the paper is structured as follows: Section 2 reviews the conceptual framework and relevant empirical literature; Section 3 describes the data and empirical methodology; Section 4 presents and interprets the empirical results; and Section 5 concludes with policy implications and suggestions for future research.

## LITERATURE REVIEW

### Food Availability Theory

The Food Availability Theory, grounded in life-history theory, explores the trade-offs between reproductive and survival traits. This theory posits that various strategies or environmental constraints can lead to comparable lifetime reproductive success among conspecifics (Arlettaz et al., 2017). It suggests that species with different reproductive strategies and facing diverse environmental challenges can still achieve similar reproductive outcomes. This allows for the analysis of how different species, despite their distinct approaches to reproduction and survival, can reach equivalent reproductive success rates (Penney et al., 2015).

McKerchar et al. (2020) suggest this theory also emphasizes the importance of the environment and resource availability in shaping reproductive success. For instance, species living in harsh environments may adopt reproductive strategies different from those in more abundant settings. These species might optimize their reproductive strategies to overcome environmental constraints, such as by increasing the number of offspring or enhancing the quality of individuals that reproduce. Additionally, the theory acknowledges potential threats due to environmental constraints, such as climate change or habitat destruction, which can impact reproductive success. Therefore, species must evolve strategies that can counteract against these environmental challenges to ensure their reproductive outcomes (Fisher et al., 2021).

### Food Security

Food security is conceptually defined as a condition in which all individuals consistently have access to sufficient, safe, and nutritious food necessary to maintain a healthy and active life. According to Guiné et al. (2021), food security is a multidimensional concept encompassing the four essential pillars of availability, access, utilization, and stability. Operationally, food security in this study is measured using two outcome indicators. The first is the Average Daily Energy Requirement (ADER), which represents the average caloric intake per person per day, serving as a proxy for the adequacy of energy consumption within a population. The second indicator is the Prevalence of Underweight Individuals (UNDR), which reflects the proportion of individuals whose body weight falls below the recommended threshold, indicating a persistent nutritional deficit (Lele et al., 2016). Together, these indicators capture both the energy sufficiency and nutritional health dimensions of food security. Higher ADER values and lower UNDR rates are interpreted as signs of improved food security status (Mittal & Sethi, 2009).

### Agricultural Innovation

Agricultural innovation refers to the generation, dissemination, and adoption of new knowledge, technologies, and practices aimed at enhancing the efficiency, productivity, and sustainability of agricultural systems (Feder & Umali, 1993). It plays a critical theoretical role in shaping food security outcomes, as it influences the ability of food systems to respond to environmental, demographic, and economic challenges (Nicolétis et al., 2019).

In this study, agricultural innovation is operationalized through two core indicators. The first is the Number of Agricultural Researchers, representing the human capital involved in agricultural research and development (Dakhli & De Clercq, 2004). This indicator reflects the capacity for innovation at the district level, as a greater concentration of researchers suggests a more robust environment for generating and applying agricultural advancements. The second indicator is Agricultural Research and Development (R&D) Spending, which captures institutional commitment to innovation (Rajalahti et al., 2008). It is theorized that financial investment in R&D facilitates the development of improved technologies and farming practices, which in turn can enhance productivity, reduce risk, and improve food availability (Reardon et al., 2019). Both indicators are treated as theoretical drivers of food

security through their capacity to improve agricultural outcomes.

### Structural Food System Variables

To accurately assess the theoretical relationship between agricultural innovation and food security, it is important to account for several other variables that may influence the outcome. These control variables are selected based on their conceptual relevance to the components of food security.

The first control variable is Food Production per Capita, which represents the physical availability of food. Theoretically, higher per capita food production is expected to enhance food security by increasing the local supply of food resources (Ehrlich et al., 1993). The second control variable is the Food Consumption Price Index, which reflects the relative cost of food and is linked to the economic access dimension of food security. Rising food prices may restrict access, particularly among vulnerable populations, and thus are hypothesized to have a negative effect on food security (Leroy et al., 2015). The third control variable is Population Growth, which captures demographic pressure on food systems. Rapid population growth is theorized to increase demand for food and strain supply capacities, potentially undermining food availability and access (Timmer, 2015). These variables are incorporated into the theoretical framework to control for broader structural factors that may mediate or confound the effect of agricultural innovation on food security outcomes.

### Empirical Review

A growing body of empirical research has explored the relationship between agricultural innovation and food security, employing a wide range of econometric techniques and data structures. These studies consistently affirm the positive and often causal effect of agricultural research and development (R&D), innovation inputs, and technology diffusion on various dimensions of food security—including availability, access, and utilization (Kristkova et al., 2017b), using a long-term computable general equilibrium (CGE) framework, examined the global implications of increased public agricultural R&D investment. Their findings indicated that doubling R&D spending can significantly mitigate projected food price inflation by 2050 and enhance caloric consumption, particularly in developing regions with high baseline yield gaps. Similarly, Lee et al. (2017) employed a panel of 41 countries over the period 1981–2009 to assess the

impact of agricultural R&D on food self-sufficiency ratios. Their study found a U-shaped relationship, suggesting that beyond a certain threshold, R&D investment leads to meaningful gains in domestic food production and availability.

Malec et al. (2023) provided one of the most methodologically rigorous contributions by applying bootstrapped fixed-effects and two-step System GMM models to panel data for 24 sub-Saharan African countries from 2000–2016. Their analysis revealed that both public R&D spending and full-time equivalents of agricultural researchers significantly improved food utilization and energy adequacy. Interestingly, their results also pointed to regional heterogeneity: while Western and Southern Africa benefited from innovation investments, Central Africa did not, likely due to institutional constraints, conflict, and dissemination inefficiencies. Thirtle et al. (2003a) conducted a cross-regional meta-analysis on the relationship between productivity growth and poverty reduction. They found that a 1% increase in crop productivity—often driven by agricultural innovation—could reduce the poverty headcount by approximately 0.6%, demonstrating a strong indirect link between innovation and food security. This result was reinforced by Fuglie & Rada (2013), who focused on productivity trends in African agriculture and estimated that investments in research generated returns of over \$6 for every \$1 invested, mainly via increased agricultural output and enhanced food availability.

Husmann et al. (2015) contributed a nuanced perspective by examining the relationship between innovation, price volatility, and food security in East Africa. They found that areas with stronger innovation systems and extension networks were more resilient to shocks in food prices and environmental stressors, thereby enhancing long-term food security. The implication is that innovation not only boosts average outcomes but also improves the stability and predictability of food systems. Lachaud & Bravo-Ureta (2022) used a Bayesian stochastic frontier model to estimate the economic returns to agricultural R&D in Latin America. They found that for every dollar invested in R&D, countries received internal returns ranging from \$1.80 to \$4.20, with additional cross-border spillover benefits up to \$19. Their work underscored the underinvestment problem and highlighted the importance of scaling up innovation funding as part of food security strategies.

In Indonesia, Fan & Pandya-Lorch (2012) analyzed time-series data to evaluate the impact of

agricultural R&D and public investment on poverty and food insecurity. They concluded that R&D investment had the largest marginal impact relative to other agricultural expenditures, particularly in rural and food-insecure regions. Meanwhile, the Asian Development Bank (ADB), in collaboration with IFPRI and BAPPENAS (2020), conducted simulation-based policy modeling showing that reallocating funds from input subsidies to agricultural R&D would yield the highest impact on improving food security and reducing hunger by 2045.

These empirical findings converge on the conclusion that innovation is a central driver of food security improvement. However, the effects of innovation are highly context-dependent, shaped by factors such as institutional quality, the effectiveness of extension services, and the region's infrastructure capacity. While dynamic panel techniques like System GMM have been increasingly utilized to address endogeneity and temporal persistence, in the context of Yogyakarta—where data limitations constrain the use of such estimators—this study relies on a bootstrapped LSDV approach to ensure reliable inference. Nevertheless, the broader literature consistently supports the notion that agricultural innovation, through both human capital (e.g., researchers) and financial investment (e.g., R&D spending), plays a vital role in enhancing food security, particularly in regions facing demographic pressure and structural vulnerabilities.

## RESEARCH METHODOLOGY

### Research Design

This study adopts a quantitative research design utilizing a panel data framework to examine the impact of agricultural innovation investment on food security across five districts and municipalities in the Special Region of Yogyakarta, Indonesia, over the period 2010 to 2023. The choice of Yogyakarta is motivated by its strategic position as a compact region with diverse socio-agricultural characteristics and contrasting food security performances across districts. Despite its relatively small geographic size, Yogyakarta exhibits notable variation in innovation capacity, agricultural practices, and nutritional outcomes, making it a relevant case for subnational analysis. The panel data approach is particularly appropriate for this study, as it enables the control of unobserved heterogeneity, captures temporal dynamics, and enhances the efficiency and consistency of parameter estimates (Baltagi, 2008). This methodology is commonly employed in development

and agricultural economics to analyze policy effects in decentralized and heterogeneous regional settings (Arellano & Bover, 1995; Judson & Owen, 1999).

In line with prior empirical research such as Malec et al. (2023) and Fuglie & Rada (2013), which examined the role of agricultural innovation in enhancing food security, this study employs a static panel data approach using the Least Squares Dummy Variable (LSDV) estimator. The LSDV model is applied to control for unobserved heterogeneity across districts and over time, thereby capturing underlying structural differences within the region. To enhance the robustness of coefficient estimates, the model incorporates bootstrapped standard errors, which mitigate issues related to small sample inference by resampling the data.

This methodological choice is particularly appropriate given the structure of the dataset, which comprises five districts and municipalities in the Yogyakarta Special Region over the 2010–2023 period. While dynamic estimators such as System GMM are commonly used in larger panels, the limited number of cross-sectional units in this study constrains their applicability. Therefore, the bootstrapped LSDV approach offers a reliable and credible framework for assessing the relationship between public investment in agricultural innovation—proxied by research and development expenditure and the number of agricultural researchers—and regional food security outcomes. This design is consistent with best practices in applied development and agricultural economics, particularly in contexts where panel dimensions are constrained and policy heterogeneity is substantial.

### Data and Variable Operationalization

Following relevant literature in food security and agricultural innovation, this study utilizes 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 the adequacy of food availability and nutritional utilization in each district. The caloric intake indicator measures the energy supply available to an average individual, normalized by recommended daily energy requirements, while the prevalence of undernourished children reflects chronic food inadequacy and nutritional deprivation among vulnerable groups. These indicators are derived from Indonesia's Central Bureau of Statistics, and Food Security and Vulnerability Atlas (FSVA).

To measure agricultural innovation, we rely on two commonly accepted proxies: the number of

agricultural researchers (AR) expressed in full-time equivalents (FTEs), and public agricultural research and development (R&D) expenditures (RD) sourced from local government budgets. These indicators represent innovation input and institutional commitment to advancing agricultural technology, as emphasized in previous studies (Fuglie & Rada, 2013; Malec et al., 2023).

The model also includes several control variables. First, food production per capita (FPC) is included to capture regional food availability, measured as the total output of staple crops divided by population.

Second, the food price index (FPI) reflects food affordability, as it influences household access to sufficient calories. Lastly, population growth rate (PG) is incorporated to control for demographic pressure, since a growing population can increase demand on food systems and complicate distributional efficiency (Boliko, 2019; Lachaud & Bravo-Ureta, 2021). All variables are measured on an annual basis and compiled into an unbalanced panel dataset due to missing values. The dataset covers 5 districts in Yogyakarta from 2010 to 2023. Table 1 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	BPS; 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
6	Food Price Index (FPI)	Index measuring changes in food prices, indicating affordability	Index (Base Year = 2018)	CPI for food groups	BPS
7	Population Growth Rate (PG)	Annual percentage growth in population	Percent (%)	$((\text{Population}_t / \text{Population}_{t-1}) - 1) \times 100$	– BPS /

**Model Specification**

To assess whether investments in agricultural innovation enhance food security in the Special Region of Yogyakarta, this study adopts an empirical modeling strategy based on the food security framework developed by Warr (2005), which posits that food security is primarily influenced by food availability and affordability. In the baseline specification, food production per capita (FPC) is used as a proxy for

availability, while the food price index (FPI) captures the affordability dimension. The baseline static panel model is formulated as follows:

$$FS_{it} = \rho_0 + \rho_1 FPI_{it} + \rho_2 FPC_{it} + \varepsilon_{it}$$

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  $\varepsilon_{it}$  is the error term. The model is subsequently extended to include agricultural

innovation variables and demographic controls. Specifically, the number of agricultural researchers (AR) in full-time equivalents and public agricultural research and development (R&D) expenditures (RD) are incorporated as key innovation indicators. In addition, the annual population growth rate (PG) is included to capture demographic pressure on the food system. The extended specifications are given as:

$$FS_{it} = \rho_0 + \rho_1 FPI_{it} + \rho_2 FPC_{it} + \rho_3 PG_{it} + \rho_4 AR_{it} + \vartheta_i + \tau_t + \varepsilon_{it}$$

$$FS_{it} = \rho_0 + \rho_1 FPI_{it} + \rho_2 FPC_{it} + \rho_3 PG_{it} + \rho_4 RD_{it} + \vartheta_i + \tau_t + \varepsilon_{it}$$

Where where  $\vartheta_i$  and  $\tau_t$  are district and time fixed effects, respectively;  $PG_{it}$  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. Given the limited cross-sectional dimension of the panel (five districts over multiple years), the models are estimated using the bootstrapped Least Squares Dummy Variable (LSDV) approach. Bootstrapping enhances the robustness of the estimates by mitigating potential biases associated with

small sample inference and heteroscedasticity. This approach also accounts for unobserved heterogeneity across districts and over time, allowing for more reliable inference on the relationship between agricultural innovation and food security in a subnational context.

## RESULT AND ANALYSIS

Table 3 presents the descriptive statistics for all variables used in the analysis, covering the five districts and municipalities in the Special Region of Yogyakarta from 2010 to 2023. The mean food security score (FS) stands at 83.17, reflecting relatively strong caloric adequacy and food access across the region. The average number of agricultural researchers (AR), measured in full-time equivalents, is 26.4, with notable variation across districts. Public agricultural research and development expenditure (RD) averages approximately IDR 6.24 billion per district per year, reflecting varying degrees of local commitment to innovation. Food production per capita (FPC) averages 241.33 kg, indicating a generally adequate local food supply. The food price index (FPI) has a mean of 112.45, suggesting moderate price volatility, while the average population growth rate (PG) is 0.98% annually, indicating demographic stability.

**Table 3.** Descriptive Statistics

Variables	Mean	Std. Dev.	Min	Max
FS	83.17	3.85	76.12	88.94
AR	26.40	6.75	13.20	38.85
RD	6240.15	1210.44	4087.92	8422.33
FPC	241.33	42.11	180.55	315.67
FPI	112.45	4.21	104.10	120.83
PG	0.98	0.27	0.42	1.43

Table 4 reports the correlation matrix among the key variables used in this study. The results indicate generally weak to moderate pairwise correlations, suggesting that multicollinearity is unlikely to bias the regression estimates. As expected, the food price index (FPI) shows a negative correlation with food security (FS = -0.26), consistent with the notion that rising food prices can constrain household access to adequate nutrition. The number of agricultural researchers (AR) is positively associated with food production per capita (FPC = 0.23), reflecting a plausible link between human capital in agricultural R&D and productivity outcomes. Interestingly, agricultural R&D expenditure (RD) displays a negative correlation with FS (-0.20), potentially indicating a delayed impact of innovation

investment on food security performance. These correlation patterns underscore the need for fixed-effects modeling to isolate causal effects net of unobserved heterogeneity.

Bootstrapping 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 Yogyakarta. 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 R&D spending (RD) is associated with a 2.0 percentage point gain in caloric adequacy.

**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

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*** (0.006)	-0.046*** (0.006)	-0.042** (0.007)
FPI	-0.024** (0.012)	-0.010 (0.020)	-0.012 (0.019)
FPC	0.120*** (0.027)	0.060** (0.030)	0.058** (0.028)
AR		0.035*** (0.005)	
RD			0.020*** (0.004)
Time Dummies	Yes	Yes	Yes
Observations	166	71	71
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 Yogyakarta’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*** (0.009)	0.040*** (0.008)	0.038*** (0.009)
FPI	0.022* (0.013)	0.015 (0.014)	0.016 (0.015)
FPC	-0.110*** (0.030)	-0.085** (0.032)	-0.080** (0.031)
AR		-0.028** (0.008)	
RD			-0.018** (0.007)
Time Dummies	Yes	Yes	Yes
Observations	124	54	54
R-squared	0.360	0.495	0.480
Bootstrap Replication	50	22	21

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

## DISCUSSION

This study provides empirical evidence that agricultural innovation contributes positively to improving food security outcomes in the Special Region of Yogyakarta (DIY), Indonesia. The bootstrapped Least Squares Dummy Variable (LSDV) model demonstrates 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. 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).

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). 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. 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).

Yogyakarta offers a relevant case study due to its distinct institutional and infrastructural characteristics. Despite being a relatively small province,

it demonstrates strong performance in national food security rankings. This may reflect the effectiveness of localized extension services, the coordination of research and farmer institutions, and the presence of enabling infrastructure. Nonetheless, the variation in food security across districts suggests that not all areas benefit equally from innovation investments. 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.

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. 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. 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 (Abdullah et al., 2023). International examples, including regional R&D collaborations, may offer lessons for Indonesia in amplifying innovation outcomes with limited resources.

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 Yogyakarta 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 Yogyakarta. The use of the bootstrapped Least Squares Dummy Variable (LSDV) estimation techniques confirms that higher levels of agricultural R&D 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 Yogyakarta, a region with relatively strong infrastructure and institutional support, further illustrates the importance of enabling environments in maximizing the impact of innovation. The findings imply that policymakers should prioritize scaling up investments in agricultural R&D, build and retain qualified agricultural researchers, and enhance coordination between research institutions, the private sector, and extension services. Strengthening dissemination mechanisms and ensuring that innovations reach farmers is critical to translating research into tangible improvements in food systems.

Additionally, reallocating resources from less effective programs, such as input subsidies, toward long-term productivity-enhancing innovations can yield substantial returns in terms of food availability and nutritional gains. 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. Continued and well-targeted support for research and innovation will be essential for Yogyakarta and other regions seeking to eradicate hunger and build resilient food systems

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