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Reorienting Public Agriculture R&D to Achieve Resilient and Sustainable Food and Agriculture Systems in Indonesia

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ABSTRACT

Indonesia's agriculture is evolving towards modern, high-value, and market-driven practices, aligning with Sustainable Development Goals (SDGs). Technological change, markets, institutions, climate change, and government policies influence the performance of agriculture. The government plays a major role in agricultural innovation through investment in agricultural research and development (R&D), focusing on food and nutrition security, climate resilience and sustainability, and agricultural transformation. This paper aims to analyze the level and structure of agricultural R&D funding in Indonesia and draw recommendations for reorienting future agriculture R&D priorities. The analysis is based on a series of focused group discussions and secondary data from related stakeholders, enriched by information from the literature review. This study assesses Indonesia's agricultural R&D funding, finding it minimal at less than 0.2% of agricultural GDP, mostly public-funded. Farmers are slow to adopt these innovations despite substantial spending on technology dissemination. Gaps exist in accelerating agricultural transformation and technology adoption. Based on the findings, we propose seven recommendations for reorienting the R&D funding, including increasing the funding level of public research and better disseminating research results. Future research agenda should cover strategic areas related to climate change, environment, and nutrition.

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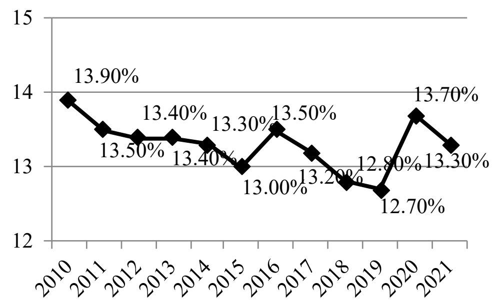
I. INTRODUCTION

Indonesia is predicted to be the fourth-largest emerging market economy globally by 2050 (IFC, 2018). The agriculture sector is the backbone of the Indonesian economy, with its share of the national GDP) of about 13.31% in the last two decades (Figure 1). This sector has played an important role in improving farmers' welfare, reducing poverty, supporting manufacturing sector growth, and being key to food and nutrition security. Agricultural practices today must comply with sustainable development principles and support the pillars of the Sustainable Development Goals (SDGs) targeted to be achieved by 2030, particularly "no poverty and zero hunger." Achieving this goal depends on food provision and agricultural performance, which rely on technological change, markets, institutions, climate change mitigation, and government policies.

Indonesia has shifted the structure of agricultural production from traditional to modern agriculture with higher value, more commercialized, and market-oriented commodities (Sudaryanto et al., 2022; 2023). Transformation of the agriculture sector in Indonesia is also needed to meet the consumption demand of the growing population and provide safe and healthy food with a balanced nutritional composition and high economic value. The government plays a major role in agricultural innovation through investment in agriculture research and development (R&D). The government budget provides the majority of the financing for R&D in Indonesia (90.71%), with the remaining 9.3% coming from grants and loans. Both public and private sectors create a mutually exclusive function in developing basic research and innovation and improving the dissemination process. In the past, public agricultural R&D in Indonesia was led by the Indonesian Agency for Agriculture Research and Development (IAARD), but since 2022 this function has been integrated into the National Research and Innovation Agency (BRIN). Meanwhile, the private sector focuses more on product research and market delivery.

This paper analyzes the level and structure of agriculture R&D funding in Indonesia and draws recommendations for reorienting future agriculture R&D priorities. The paper is organized as follows: after the introduction, the second section describes the basic methodology. In the following section, we highlight the major results of the analyses. Finally, in the last section, we list the main conclusions and recommendations.



Source: The World Bank, 2021

Figure 1. Contribution of agriculture, forestry, and fishery to Indonesian GDP, 1990-2020 (%)

II. RESEARCH METHOD

A. Data Sources

Data were derived from primary and secondary sources. Primary data were collected through in-depth interviews (in person or via call and virtual platforms) with representatives from the public and private sectors, fieldwork through ocular surveys, and discussions with other relevant key informants/institutions.

Table 1. Thematic areas of R&D spending

Impact	Description	Output
Productivity	R&D activities aiming to improve productivity by increasing crops production and livestock reproduction efficiencies through the use of technology, including plant breeding, cultivation techniques, fertilization, pests/diseases/weeds control, water management (irrigation), harvest and postharvest (processing), agri-tech, and other related technical aspects.	Area, production, productivity (selected commodities)
Nutrition	R&D focuses on improving the nutritional quality of plants and livestock, including the edible matter's nutrient enrichment and contamination prevention.	Dietary energy adequacy, desirable dietary patterns, the prevalence of stunting, etc.
Climate resilience	R&D aims to anticipate, respond to, and mitigate hazardous events, trends, or disturbances related to climate by assessing how climate change will create new or alter the current risks and then finding solutions to protect crops and livestock from the risks.	Anticipation, mitigation, and other related actions
Environmental sustainability	R&D on natural resources management to restore and prevent soil, water, and land degradation, preserve the environment, and enhance the quality of life	Sustainable environment

Source: Sudaryanto et al., 2022

Secondary data were gathered from Indonesian government institutions, including the Ministry of Agriculture (MoA), the Central Bureau of Statistics (BPS), and other related institutions. Both data were collected using questionnaires, interview guidelines, field notes, and recording devices.

B. Data Analysis

The data were analyzed using a descriptive method based on the key issues in food and agriculture R&D, i.e., spending (budget allocations), trends, themes, and impact areas. Those were compiled to identify the shifts in public R&D management to achieve sustainable, sufficient, and climate-resilient food systems in Indonesia.

The following mechanisms and assumptions were employed: (1) Data were collected across research centers in the IAARD as a predominant institution (>90%) managing food and agriculture R&D in the country. All data were analyzed based on the available time series (2015-2020). (2) The R&D spending was measured in Indonesian currency (IDR) and converted to US dollars (USD) using the official exchange rate in the corresponding years and deflated by the latest consumer price index (2018=100) to counterbalance the inflation and deflation. The real R&D spending was also computed by the share ratio to determine the percentage of the trend toward policy intervention. (3) The themes and impact of R&D were clustered into (a) Thematic areas adopted from the Indonesian Ministry of Research, Technology and Higher Education/Kemenristekdikti (2017) (Table 1); and (b) Impact areas identified with research partners by analyzing the research titles of funded programs (Table 2). The following commodities were selected for analysis, namely: (a) Rice, maize, and soybean (food crops); (b) Mango, shallot, and chili (horticulture); (c) Coffee and cocoa (estate crops); and (d) Poultry and beef (livestock).

III. RESULTS

A. Transformation of Agricultural R&D Structure and Management

Currently, Indonesia is restructuring its R&D systems, including agriculture and food. The IAARD-MoA is transformed into the National Research and Innovation Agency (BRIN). This is regulated by Presidential Regulation Number 78/2021 as mandated by Law Number 11/2019 on the National System of Science and Technology. The main reason for establishing this Agency is to carry out research and development in the country in an integrated manner to avoid overlapping and increase efficiency.

This national R&D transformation requires policy and program synergy with central and regional government agencies as well as partnerships with the private sector, academia, and community-based organizations. Considering that the agricultural sector in Indonesia is characterized by diverse natural resources and small-scale agriculture with various limitations, this agricultural R&D transformation needs to be accompanied by an appropriate technology delivery system to serve the technological needs with specific locations and ecosystems.

Table 2. Impact areas of R&D spending

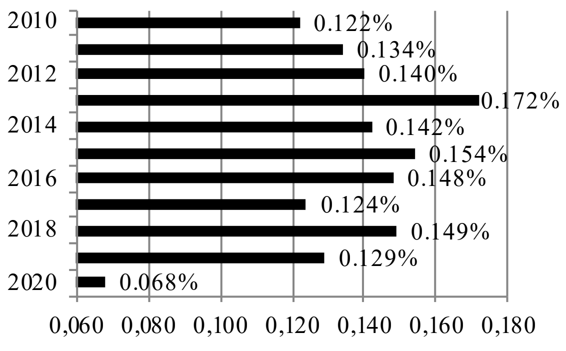
Impact	Description	Output
Productivity	R&D activities aiming to improve productivity by increasing crop production and livestock reproduction efficiencies through the use of technology, including plant breeding, cultivation techniques, fertilization, pests/diseases/weeds control, water management (irrigation), harvest and postharvest (processing), agri-tech, and other related technical aspects.	Area, production, productivity (selected commodities)
Nutrition	R&D focuses on improving the nutritional quality of plants and livestock, including the edible matter's nutrient enrichment and contamination prevention.	Dietary energy adequacy, desirable dietary patterns, the prevalence of stunting, etc.
Climate resilience	R&D aims to anticipate, respond to, and mitigate hazardous events, trends, or disturbances related to climate by assessing how climate change will create new or alter the current risks and then finding solutions to protect crops and livestock from the risks.	Anticipation, mitigation, and other related actions
Environmental sustainability	R&D on natural resources management to restore and prevent soil, water, and land degradation, preserve the environment, and enhance the quality of life	Sustainable environment

B. Trend and Structure on Agriculture R&D Spending

Over the last six years (2015-2021), the total average agricultural R&D spending was USD131.5 million per year, with a declining trend largely due to COVID-19. The share of food and agricultural R&D spending in the total agricultural GDP from 2010 to 2020 has been low (on average 0.135%), with an annual growth of about -3.25% (Figure 2). This is far behind the global average of 1% in developing countries and 2% in developed countries. Likewise, it is also lower than other ASEAN countries such as Thailand (0.94%), Malaysia (0.85%), and even Vietnam, i.e., 0.20% (Stads et al., 2020).

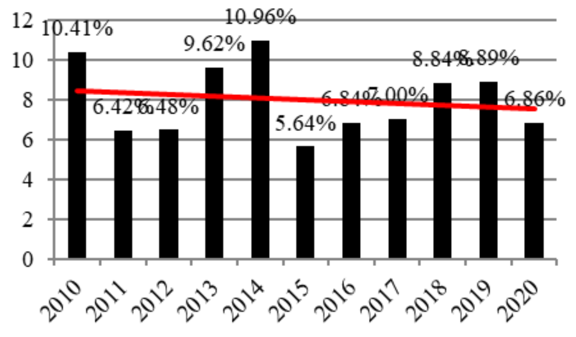
Up to 2021, more than 90% of agricultural R&D activities were carried out by IAARD. The main funding source came from the State-owned Budget (APBN) and Non-Tax State Revenue (PNBP). Other sources were grants (8.75%) and loans (0.54%). However, due to the COVID-19 pandemic, R&D spending decreased by almost half from the government (APBN and PNBP), close to 43.9%, reducing from loans while all grants were halted. Indonesia receives loans from donors (financial lenders) like the World Bank, IFAD, and ADB, while grants are designed under bilateral cooperation (ACIAR, CIDA), regional (ASEAN, ESCAP-CGPRT), or multilateral schemes (CG centers, e.g., IFPRI, IRRI, CIAT, ILRI). The IAARD budget was spent on the following areas (in decreasing order): (1) Research, (2) Research technical support, (3) Operational activities, and (4) Maintenance.

The proportion of agricultural R&D spending in the MoA expenditure was about 8% per year (Figure 3). The varying amounts depended on the implemented programs during specific years. For instance, the spending in 2010 and 2014 was higher than in other years due to agricultural tools and machinery procurement.



Source: IAARD, 2021

Figure 2. Share of R&D spending on food and agriculture to agricultural GDP, 2010-2020 (%) in Indonesia



Source: MoA, 2021

Figure 3. Share of R&D spending on food and agriculture to MoA expenditure, 2010-2020 (%)

The total agricultural R&D spending can be placed in four categories: (1) Personnel costs, (2) Operation and maintenance, (3) Research and technical support, and (4) Infrastructure and capital. The spending in research and technical support accounts for 46% of the total R&D spending, which includes research and program projects, planning, monitoring and evaluation, research cooperation and dissemination, human resources management, and financial management. Personnel costs account for 29%, followed by infrastructure (15%) and operation and maintenance (10%).

IV. DISCUSSION

A. Major R&D Spending Trends by Crop, Thematic, and Impact Areas

This R&D budget allocation pattern is aligned with the government priorities of agricultural and food development. Given the importance of rice as a strategic political, economic, and social commodity in the country, it is largely targeted at developing the rice sector. Self-sufficiency in rice production has been declared one of the top priorities for national development in the National Mid-Term Development Plan (RPJMN).

The main thematic areas considered in this study comprise breeding, cultivation, postharvest, and food security. From 2015 to 2020, the highest R&D spending was on breeding technology, USD10,3 million per year (68.46% of the total agricultural R&D program for the four themes). Most (28.60%) of the R&D funding for breeding technology was allocated to rice as shown in Table 3. Above all, technologies for breeding, cultivation, postharvest, and food security are aimed at increasing productivity.

Table 3. The total amounts and shares of R&D spending by thematic areas, 2015-2020

R&D Spending	Breeding	Cultivation	Postharvest	Food Security
Food crops				
Amount [(a)]	5,396	1,705	448	906
Share [(b)]	35.81	11.31	2.97	6.01
Horticulture				
Amount [(a)]	1,530	405	170	0
Share [(b)]	10.15	2.69	1.13	0
Estate crops				
Amount [(a)]	665	268	83	0
Share [(b)]	4.41	1.78	0.55	0
Livestock				
Amount [(a)]	2,726	677	91	0
Share [(b)]	18.09	4.49	0.60	0
Total				
Amount [(a)]	10,317	3,055	792	906
Share [(b)]	68.46	20.27	5.26	6.01

Notes: (a) Amount in thousand USD; (b) Share in percentage (%)

Breeding and productivity absorbed most R&D spending, aiming to meet the domestic demand for food and agriculture products. Food crops, especially rice, received the highest funding as this strategic commodity may raise political and socioeconomic concerns in Indonesia.

The impact areas considered in this study consist of productivity, nutrition, climate resilience, and environmental sustainability. Table 4 shows that over six years (2015-2020) of the four impact areas, the largest amount of R&D funds was spent on productivity-enhancing technologies, as much as USD 13,2 million annually (88.41% of the total R&D program for the four impact areas), with the majority allocated to food crops, mainly rice. Spending on nutrition, climate resilience, and sustainability was comparatively minor. Our analysis also revealed that implementation at the field level was not optimal, as farmers had not fully adopted available R&D technologies. The gaps faced by small-scale farmers and food consumers remain unaddressed by the current public R&D system.

Table 4. The total amounts and shares of R&D spending by impact areas, 2015-2020

R&D Spending	Breeding	Cultivation	Postharvest	Food Security
Food crops				
Amount [(a)]	7,477	317	110	264
Share [(b)]	50.05	2.12	0.74	1.77
Horticulture				
Amount [(a)]	1,724	144	160	131
Share [(b)]	11.54	0.96	1.07	0.88
Estate crops				
Amount [(a)]	924	45	0	38
Share [(b)]	6.18	0.30	0	0.25
Livestock				
Amount [(a)]	3,084	140	87	295
Share [(b)]	20.64	0.94	0.58	1.97
Total				
Amount [(a)]	13,209	646	357	728
Share [(b)]	88.41	4.32	2.39	4.87

B. Major R&D Output and Its Adoption by Smallholder Farmers

The objectives of agriculture development have remained largely the same in the last three development cycles (five years per cycle): improving farmers' welfare, providing sufficient food for the population, supporting national economic growth, and reducing rural poverty. Therefore, IAARD's R&D plan also targets these objectives (IAARD, 2010, 2016, 2020).

Agriculture actors are mainly small-scale farmers, especially in the food crops, horticulture, and livestock subsectors. Based on the 2018 Inter-Census Agriculture Survey (SUTAS), the number of farm households in Indonesia was 27.68 million, with each household often participating in more than one farming activity. Statistics Indonesia (BPS, 2021a) reported that of the total farm households, 73.27% work in food crops, 43.61% in estate crops, and 36.43% in horticulture. Farm households' average farm size was 0.18 hectares of lowland (suitable for rice farming) and 0.55 hectares of dry land. The proportion of households with ownership of less than 2.0 hectares, categorized as small-scale, was 89.1%. Based on Law Number 19/2013 on Protection and Empowerment of Farmers, a small-scale food crops farmer is set a maximum landholding size of 2.0 hectares.

Since small-scale farming is predominant in Indonesia, IAARD prioritizes this segment as the primary beneficiary of the technologies and inventions. However, small-scale farmers are often associated with low education, limited access to financial and production sources, and becoming an aging population. For example, in 2018, more than 60% of farmers completed or dropped out of primary school, and more than 35% were over 55 (BPS, 2018). With these characteristics, small-scale farmers have less capacity and ability to properly adopt new agricultural technology and innovation.

One of the main research programs of IAARD is breeding new varieties of high-yielding food crops, horticulture, estate crops, and livestock breeds. This breeding activity was mainly concentrated on food crops prioritized by the Ministry of Agriculture. A common thread among the variety-enhancement programs by IAARD is the aim to (1) achieve food security and nutrition fulfillment by generating higher productivity, product quality, and nutrition content; (2) adapt to climate change by increasing plants' tolerance to droughts and floods, as well as land salinity and acidity; and (3) improve sustainability by suiting plants to local agroecosystems (IAARD, 2010, 2016, 2020b). There is a strong contribution from grants that IAARD received; for example, IRRI has been helping IAARD to improve new rice varieties with the above-mentioned attributes.

Rice is a major food crop in Indonesia and its consumption is still substantial, suggesting that daily nutritional intake depends on cereals. It leads to health problems in Indonesia such as poor health, anemia, and diabetes. Increasing the nutritional value of rice through crop improvement is an important strategy to reduce the prevalence of malnutrition. Improvements in the nutritional value of rice varieties have been achieved through the development of antioxidant-rich pigmented rice, micronutrient-rich rice, and low glycemic index (GI) rice varieties (Sitaresmi et al., 2023). For 17 years (2005-2021), IAARD has created 117 new superior rice varieties suitable for various agroecosystems, 112 other food crops varieties (such as maize, soybeans, peanuts, mung beans, sorghum), 63 vegetable varieties (such as shallot, chili, green beans, mushrooms. tomatoes), 84 fruit varieties (such as oranges, mangoes, bananas, papaya, and melons), 130 estate crop varieties including coffee, cocoa, sugarcane, spices, and medicinal plants, and six superior livestock breeds (IAARD, 2010, 2016, 2020b, 2021; ICCRI, 2022).

Several technology packages have been assembled aimed at improving farming systems based on specific commodities and agroecosystems; crop protection and pest management; sustainable agriculture, including fertilizer use efficiency and adaptation to climate change; postharvest technology, primarily to support food diversification and create healthy food; and agricultural tools and machinery creation to increase productivity and efficiency for a local specific environment. At the same time, the technology development seeks to improve the efficiency of land and water resources and input use leading to more sustainable agriculture. In the livestock sub-sector, one of the research topics was to enhance feed composition for poultry and ruminants using local materials (IAARD, 2020a, 2021).

Among the key adaptation measures, adjusting the harvest calendar could be a viable and effective solution to offset the negative impacts of climate change on crop yields Wang et al (2022). An example of a technology package designed by IAARD and widely adopted by local officials and farmer groups is the Information Systems of Integrated Cropping Calendar, called *Kalender Tanam* or KATAM. This Cropping Calendar is an adaptation approach to the impacts of climate change. The KATAM offers essential information covering all sub-districts in Indonesia about (1) Early prediction of planting time; (2) estimation of planting area; (3) flood and drought-prone areas; (4) areas with potential pest outbreak; (5) recommendation of plant varieties; and (6) recommendation of locally specific balance fertilizers (Ramadhani *et al*., 2013; Runtunuwu *et al*., 2012; Apriyana *et al*., 2021.

The KATAM technology package improved yearly cropping patterns, planted acreage/cropping index, and crop productivity and food production (Fahri et al., 2018; Murni and Purnama, 2020). Furthermore, this technology package can also avoid production risks in rice farming, such as yield loss due to flooding or drought (Fahri and Yusuf, 2019). However, more efforts are still needed to ensure farmers adopt the recommendation of farming practices from the KATAM. This is due to wide differences in resource availability owned by farmers and the variability of farming practices in each region (Yulianti et.al., 2016).

The postharvest R&D of IAARD is to increase the added value and diversity of processed food to support food security and nutrition through local staple food diversification. Postharvest technologies created by IAARD are designed for micro, small, and medium enterprises (MSMEs) since a large proportion of MSMEs in the country (43.6% out of 4.21 million MSMEs) was in the food business (BPS, 2021b). One example of this postharvest technology is the product development of flour starch from local food sources such as cassava, sweet potatoes, maize, banana, sago, and breadfruits suitable to be used as raw material for processed food by MSMEs. This local food flour can substitute or complement imported wheat flour as raw material for the food processing industry.

R&D activities and technologies mentioned thus far are designed and directed to increase small-scale farmers' productivity, efficiency, and farm income. However, productivity is determined in the fields by improved seeds, breeds, and farming system technology alone and by the environment surrounding farming fields, technically, economically, and socially (Kakar et al., 2016; Rachmina et al., 2013). Aside from that, productivity also depends on the capacity and capability of farmers to adopt and apply new technologies and government policies such as investment in agriculture infrastructure, farmer empowerment, and farming incentives such as input subsidy or output price certainty. Factors determining the technology adoption by farmers include the potential profitability generated from the use of technology, the technical suitability of the technology with farmers' preferences and local conditions, and the farmers' technical and economic capacity and capability to implement the technology (Hailu et al., 2014; Mardiharini et al., 2021; Pannell et al., 2006; Pratiwi et al., 2018).

Dissemination of agriculture technology and innovation is one of' AARD's essential tasks. This function is carried out by the Assessment Institute for Agriculture Technology (AIAT) in 33 provinces. AIATs' service area covers the entire territory of Indonesia, so the budget allocation to all AIAT's activities in the last five years absorbed one-third of the budget allocation for IAARD. The functions of AIATs, among others, were to identify and to make an inventory of farmers' agriculture technology needs in specific areas, prepare extension materials of the introduced technology, and 4 identify feedback for introduced technology for further improvement.

AIATs work with local provincial and district-level agricultural offices, researchers, and extension workers to carry out these tasks. Behavioral change underlies this implementation. An example of this effort is a pilot program for the acceleration of agricultural innovative technology called PRIMATANI (stands for *Program Rintisan dan Akselerasi Pemasyarakatan Inovasi Teknologi Pertanian Pertanian*) first introduced by IAARD in 2006. The dissemination method aimed to accelerate farmers' adoption of new agriculture technologies to increase productivity, efficiency, and competitiveness in rural areas (IAARD, 2006a). The working principle of PRIMATANI consists of: (1) An assessment of local resources' potential and technology that can help optimize these resources; (2) A selection of suitable agribusiness development programs and technology intervention; (3) The creation of a pilot model for the innovative technology-based agribusiness systems; (4) Implementation that integrates innovation, institutional systems, and agribusiness systems. In implementing the PRIMATANI, two or three researchers were dispatched to stay and mingle with the community in the village for several months over a year. In collaboration with extension workers, these researchers acted as mentors in the program implementation (IAARD, 2006b).

The pilot program PRIMATANI had positive impacts on farming practices (Anugrah, 2022; Arya et al., 2014, Kamandalu et al., 2012; Drajat, 2009). For example, on rice farming, the improvement was indicated by the application of balanced fertilizer, increased productivity, improved grain quality to meet market demand, livestock waste processing into organic fertilizer, and the formation of women farmers' groups. Local governments and communities well accepted this pilot program; among others provinces of Central Java and Bali have replicated PRIMATANI as a technology dissemination method (Anugrah, et al. 2014; Kamandalu et al., 2012)

Table 5 shows the gap between the potential yield of newly improved high-yielding varieties and the average yield at small-scale farming in rice, corn, soybean, shallot, chili, coffee, and cacao. In some cases, the yield gap was more than 50% (FAO, 2022; IAARD, 2022; ICCRI, 2022). Using improved seeds does not directly optimize productivity. Other factors also play significant roles, such as planting at the suitability of land, applying recommended farming practices, overcoming extreme climate change, managing pest and disease attacks, and obtaining the right product selling prices.

These facts confirm that productivity was not only determined by the availability of high-yielding variety seeds and improved farming technology but also by farmers' capability to implement a farming technology package as recommended (Listiana et al., 2021). The wide gap between potential and actual yields was also attributable to the intensity and means of technology dissemination (Handral et al., 2017; Irawan et al., 2015).

Table 5. Potential yield of improved crop varieties and actual yield at small-scale farm level for selected crops

Crop	Unit	Range of potential yield of improved varieties (ton/ha)	Range of average yield/year (2015-2020) at smallholder farm (ton/ha)
Rice	Dried paddy	6.0-10.2	5.1-5.4
Corn	Dried kernel	8.5-13,7	5.2-5.7
Soybean	Dried bean	2.9-3,8	1.3-1.6
Shallot	Fresh	17.3-29.1	9.3-10.1
Chili	Fresh	8.2-14.2	7.5-8.8
Coffee	Dried bean	2.4-2.8	0,5-0.6
Cacao	Dried bean	1.8-2.8	0,4-0,5

Source: FAO (2022); IAARD (2022); ICCRI (2022)

For 47 years, IAARD created more than 300 new rice varieties, but only a few were adopted by farmers with sizeable acreage, usually for a short period, and then replaced by new ones. As a result, only a few improved rice varieties have been popular among farmers for an extended period, more than 20 years, namely IR 64 (released in 1986 and Ciherang in 2000, and Mekongga in 2004). These rice varieties are designed for irrigated rice fields. Farmers adopted IR 64 rice variety rapidly. In 2000, 14 years since its release in 1986, IR 64 was planted in 61% of rice farming in Indonesia. However, Ciherang rice variety was released in 2000, immediately popularized, and quickly overtook IR 64. In 2010, the planted acreage of IR 64 rice variety dropped to 11.38%, while the Ciherang variety rose to 28.40%. Ten years later, in 2020, Ciherang rice still dominated the planted area at 29.85%, while IR 64 dropped to 6.30% of the total rice planted acreage. In 2020, rice producers in the country used more than 95% of improved high-yielding varieties created by IAARD as depicted in Table 6.

At the regional level, for example, in West Java, one of the central rice production provinces, Ciherang rice variety surpassed IR 64 very rapidly. Up to 2002, IR 64 variety still dominated lowland rice fields planted acreage in this province by 42%, followed by Way Apo Buru variety at 19.1% and Ciherang at 12.7%. However, since 2004, of the total planted area of 1.76 million hectares in this province, Ciherang took over the position as the largest planted variety by 39,9%, while IR 64 dropped to 27.6%, and Way Apo Buru decreased sharply to 8.8% (Nurhati et al., 2008).

Table 6. Percentage of rice planting acreage in Indonesia by varieties, 2010, 2015, 2020

Rice Varieties	Year released	2010	2015	2020	Rank in 2020
IR 64	1986	11.38	11.94	6.30	4
Ciherang	2000	28.49	30.31	29.85	1
Cigeulis	2002	6.03	4.36	3.19	7
Situ Bagendit	2003	n.a	6.58	4.11	6
Mekongga	2004	n.a	10.69	12.57	2
Inpari 30	2012	n.a	n.a	4.66	5
Inpari 32	2013	n.a	n.a	7.45	3
Other high-yielding varieties	-	41.47	26.56	25.08	-
Local varieties	-	12.63	9.86	5.89	-
Total planted area (thousand ha)	-	13.808	13.867	11.039	

Differences in the adoption rate or level of commercialization of newly introduced rice varieties are influenced by seeds' characteristics, namely productivity, suitability with consumer preferences (such as taste), high resistance to pests and diseases, and level of rice selling prices (Syahri and Somantri, 2018). A study in two provinces (West Java and East Java) reported that farmers' preferences for rice varieties are determined by short cultivation time, resistance to major pests and diseases, high productivity, and low percentage of broken rice (ICASEPS, 2022). Another study concluded that the high popularity of IR 64 and Ciherang was driven mainly by the selling prices (relatively higher than other varieties), productivity, resistance to pests and diseases, and ease of selling (Syamsiah et al., 2015). This study also found that Ciherang outperformed or scored higher than IR 64 in these four criteria. Besides consumer preferences, timely seed availability and intensive socialization of new superior seeds to farmers are key to accelerating the adoption rate (Perdana et al., 2021; Swastika et al., 2021; Syahri & Somantri, 2018). In line with those findings, proposed technologies and innovations and how they are introduced and presented to target communities are often incompatible with indigenous values, habits, socio-cultural institutions, and ways of doing things, making technology transfer challenging for farmers.

Problems faced by small-scale farmers in adopting improved technology to increase crop productivity, farming efficiency, and product competitiveness are: (1) Limited ownership and control over productive resources; (2) lack of ability and capacity to access and implement improved agricultural technologies and innovation; (3) limited farmers' financial capacity to acquire and apply new, improved technology; (4) limited accessibility to agricultural input and output markets; and (5) inability to benefit from economies of scale principle.

Based on this assessment, it can be concluded that improved agriculture technology is a prerequisite to increase farming productivity and efficiency. However, the availability of new technology will not automatically be adopted by farmers. One important factor in technology adoption is the farmers' behavior toward their farming activities. Farmer behavioral change will allow the economy of scale principle to play its role in increasing efficiency and competitiveness. Behavioral change toward more commercialized approach in farming activities is needed to organize farmers in a specific area that meets the economies of scale to develop their farming business jointly. In addition, technology dissemination and farmers' empowerment need to be accelerated, which includes knowledge and upskilling, access to technology, financial sources, information, and input and output markets.

Dissemination of agriculture technology and innovation is one of' AARD's essential tasks. This function is carried out by the Assessment Institute for Agriculture Technology (AIAT) in 33 provinces. AIATs' service area covers the entire territory of Indonesia, so the budget allocation to all AIAT's activities in the last five years absorbed one-third of the budget allocation for IAARD. The functions of AIATs, among others, were to identify and to make an inventory of farmers' agriculture technology needs in specific areas, prepare extension materials of the introduced technology, and identify feedback for introduced technology for further improvement.

AIATs work with local provincial and district-level agricultural offices, researchers, and extension workers to carry out these tasks. Behavioral change of smallholder farmers underlies this implementation. An example of this effort is a pilot program for the acceleration of innovative agricultural technology called PRIMATANI (stands for *Program Rintisan dan Akselerasi Pemasyarakatan Inovasi Teknologi Pertanian Pertanian*) first introduced by IAARD in 2006. The dissemination method aimed to accelerate farmers' adoption of new agriculture technologies to increase productivity, efficiency, and competitiveness in rural areas (IAARD, 2006a). The working principle of PRIMATANI consists of (1) An assessment of local resources' potential and technology that can help optimize these resources; (2) A selection of suitable agribusiness development programs and technology intervention; (3) The creation of a pilot model for the innovative technology-based agribusiness systems; (4) Implementation that integrates innovation, institutional systems, and agribusiness systems. In implementing the PRIMATANI, two or three researchers were dispatched to stay and mingle with the community in the village for several months over a year. In collaboration with extension workers, these researchers acted as a mentor in the program implementation (IAARD, 2006b). This approach aligns with the lesson learned from a meta-analysis of the empirical literature that concludes the efforts to promote agricultural technologies in the developing world must be adapted to suit local agricultural and cultural contexts (Ruzzante et al., 2021).

The pilot program PRIMATANI positively impacted farming practices (Anugrah et al., 2014; Arya et al., 2014; Kamandalu et al., 2012). For example, on rice farming, the improvement was indicated by applying balanced fertilizer, increased productivity, improved grain quality to meet market demand, livestock waste processing into organic fertilizer, and the formation of women farmers' groups. Local governments and communities well accepted this pilot program among others, provinces of Central Java and Bali have replicated PRIMATANI as a technology dissemination method (Anugrah et al., 2014; Kamandalu et al., 2012).

IAARD also received loans and grants to strengthen the role of AIATs as the leading institution in the process of technology dissemination and adoption across 33 offices in Indonesia. ACIAR is an example, the institution has been supported research across commodities and agroecosystems for almost 40 years, during this period the institution has been improved the capacity building of AIATs human resources through research, trainings and higher-degree scholarship. Nevertheless, the World Bank provided a loan to strengthen the role of IAARD and called the project Sustainable Management of Agricultural Research and Technology Dissemination (SMARTD) from 2015 to 2019.

C. Major Gaps in Agriculture R&D

The gaps faced by small-scale farmers and food consumers remain unaddressed by the current public R&D system. The country has experienced disruptive transformation and dynamic changes that reshaped the R&D management and strategy, including in the agriculture sector. The recent agricultural research and development transformation in Indonesia is expected to help overcome these gaps. Agriculture is expected to help countries like Indonesia achieve multiple development goals. These goals include food security,ob growth, environmental sustainability, and poverty and malnutrition reduction (Otsuka, 2021).

Major gaps in agriculture R&D to be addressed are (1) Inadequate research funding; (2) Inappropriate budget allocation across commodities and thematic areas in responding to emerging challenges; (3) Barriers to the adoption of innovation by small-scale farmers; (4) Gaps in food consumption patterns that hinder the achievement of food security and nutrition fulfillment; (5) At present institutional arrangement at BRIN has not established R&D dissemination mechanism across working units in BRIN; and (6) Weak connection and coordination between BRIN and line ministries as partners in formulating agriculture R&D strategies and delivering agricultural R&D results.

V. Conclusion

Agriculture R&D funding in Indonesia has been very small compared to peer countries in Asia. Guided by agriculture development policy, the limited budget was allocated mostly to finance agriculture R&D-related food crop production to secure food security. On the other hand, the R&D budget for high-value commodities and emerging thematic areas was much smaller. Despite the relatively small budget, much progress has been made regarding agriculture R&D outputs, but the adoption rate was relatively small due to some constraints faced by smallholder farmers.

Responding to the gaps faced by smallholder farmers and consumers, some policy recommendations are proposed, which include: (1) Increase research fund to strengthen agriculture and food R&D to promote eviden90ce-based policies at least 0.56% of national agriculture GDP by 2030 with an annual growth of about 4.99%/year; (2) Diversify funding sources for R&D programs and encourage greater private-based investment as well as collaboration; (3) Increase the share of R&D funds for high-value commodities which include horticulture, estate crops and livestock, as well as thematic areas that boost sustainable nutritious, and climate-resilient food systems; (4) Strengthen the delivery system of public R&D to farmers, in particular the mechanism of agricultural technology transfer from BRIN to users/small-scale farmers; (5) Increase the impact of R&D results for farmers and consumers by designing agriculture R&D programs that strengthen food security and nutrition as well as improving consumers' capacity to access and consume nutritious food; (6) Develop new agricultural R&D strategies, as well as coordination and communication platforms inside BRIN; and (7) Finalize the connection and coordination between BRIN and line ministries/agencies in formulating agriculture R&D strategies and utilizing agricultural R&D results.

In response to the emerging issues of climate change, environmental degradation, and nutrition, it is advisable to prioritize future research agendas in two areas: ***First***, thematic research on climate resilience, environment, and nutrition. This recommendation aligns with BRIN's current agenda to strengthen research on the green economy, blue economy, and digital technology by utilizing the circular economy approach. ***Second***, commodity research supports transforming from low-value food crops to high-value commodities. The selection of prioritized commodities should be based on the foresight analysis providing sound information on the economic prospects of the corresponding commodities.

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