Enhancing food security in Indonesia: The role of agricultural biotechnology in addressing climate change and food demand challenges

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Abstract
The Food and Agriculture Organization (FAO) documented that around 2.4 billion people were experiencing food inadequacy worldwide in 2022. Moreover, the United Nations has announced that the world population will soar to 9.8 billion people in 2050, indicating a potential food demand boost. Exacerbated by climate change, global food security issues are scrutinized by policymakers, stakeholders, and researchers globally. With around 275 million people and an escalating number of imported staple food products, Indonesia is at high risk of food insecurity. This study aims to examine the efficiency of various agricultural biotechnology practices and predict their feasibility of implementation in addressing agricultural and climate change obstacles while evaluating the socioeconomic and political impact of agricultural biotechnology implementations in Indonesia. This research employs a systematic literature review methodology to suggest agricultural biotechnology strategies and policy management for Indonesia. The results revealed significant increases in food security research, which could pave the way for Indonesia's advancements in the agricultural biotechnology sector despite the complexity of population pressure, lack of automation, insufficient arable land, and the inefficient use of fertilizers, which exacerbated the ecological damage. Therefore, investment in agricultural biotechnology is crucial as it offers comprehensive solutions to tackle the issues. In addition, the government is suggested to re-strategize the subsidy allocation in the farm sector to invest in agricultural machinery technology, human resources improvement, and agricultural research.

1. Introduction

With the significant population growth, food demand is expected to rise by more than 50% by 2050 (James Pomeroy, Davey Jose, Amy Tyler, 2023). Since the 2008 food crisis, the Food and Agriculture Organization (FAO) has recorded that nearly 1 billion people were identified as undernourished due to decades of underinvestment in agriculture and food security (FAO, 2008). The population explosion aggravates the situation, which is expected to grow to 9.8 billion in 2050, while around 2.4 billion people worldwide are experiencing food inadequacy as of 2022 (United Nations, 2023; United Nations Department of Economic and Social Affairs, 2022). Nevertheless, the current food security situation is challenged by the skyrocketing price of wheat and corn by 40-50% in the pre-war period in Russia and Ukraine. This point was repeatedly raised in the Global Report on Food Crisis 2022: Joint Analysis for Better Decisions, 2022. The report emphasizes the spread of hunger and rising food prices and notes that achieving the Sustainable Development Goals (SDG) depends on overcoming hunger and ensuring optimal food security. Moreover, fighting global hunger, addressing the food crisis, and ensuring food security at the supranational level are among the priorities of the SDG launched by the UN General Assembly in 2015 (United Nations, 2015).

In one cross-sectional study, food insecurity was associated with child stunting, which affected children 0–23 months in households that consumed more than two meals a day (Ramli et al., 2016). The prevalence of child stunting in Indonesia has remained high over the past decade, reaching around 37% at the national level (Beal et al., 2018). According to the statistics, 6.3 million Indonesian children were stunted in 2020 (Anugrah & Qonita, 2021). Therefore, reducing child stunting is a primary indicator for

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the second SDG of Zero Hunger and the first of six targets in the Global Nutrition Targets for 2025 (World Health Organization, 2006).

In most developing countries, food insecurity and a lack of access to nutritious food affect civilians' health and well-being, especially for those with low incomes (The Ministry of Food, 2016). Food prices, already high and volatile, may spike again as droughts, floods, and other climate-related events affect harvests. Countries must develop short- and medium-term responses (United Nation, 2009). Such conditions are happening in Indonesia, as evidenced by the rising prices of staple foods such as rice. With the increase in the retail price (HET) for premium and medium rice, from IDR 12,500/kg to IDR 14,900/kg (20%), the government chose to import rice to stabilize market prices (Saptowalyono, 2023).

In addition, based on BPS projection data using the Sample Area Framework (ASF) method, observed in May 2024, rice production has the potential to decline by 9.25%, or 21.39 million tons, from January to August 2024. The most significant decline occurred in June 2024, when it only reached 2.02 million tons. Furthermore, production will increase by 2.19 million tons in July and 2.67 million tons in August. In 2023, rice production reached 2.79 million tons in June, fell to 2.48 million tons in July, and then surged to 2.52 million tons in August. This condition will cause the prices to increase. Based on the Badan Pusat Statistik (BPS) data (**see Figure 1**), rice production experienced a deficit of 0.57 million tons in June 2024 and 0.43 million tons in July 2024. Therefore, Indonesia must have a program that can realize food security.

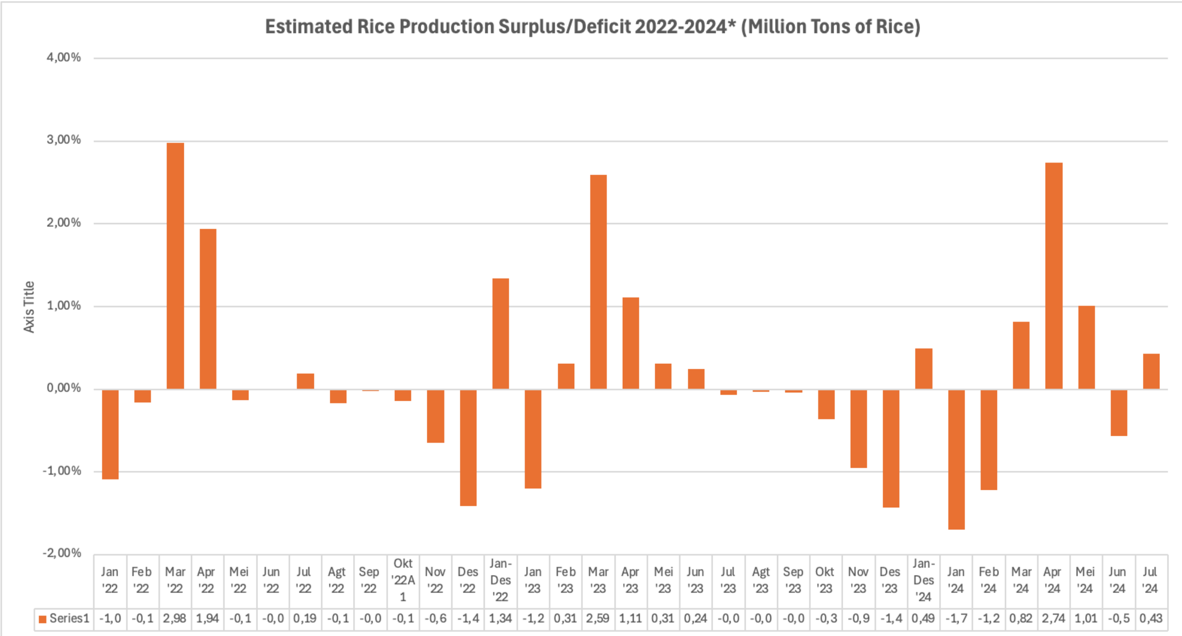

Figure 1. Surplus and deficit rice estimation. Source: Badan Pusat Statistik (2024).

According to the BPS inflation release on July 1, 2024, the average price of rice and unhulled rice continued to rise by 11.88% yoy from the beginning of 2024 to June 2024, after declining steadily from 2022. Based on data from the National Strategic Food Price Information Center (PIHPS), super-quality I rice averages IDR 16,800/kg, medium-quality I rice averages IDR 15,400/kg, and low-quality I rice averages IDR 14,550/kg. The following data on rice imports with sources from importing countries ("Rice imports by major country of origin 2017-2023, 2024) is listed in **Table 1.**

Table 1. Rice imports by major country of origin 2017-2023.

Origin Country	2017	2018	2019	2020	2021	2022	2023
India	32,209.70	337,999	7,973.30	10,594.40	215,386.50	178,533.60	69,715.70
Thailand	108,944.80	795,600.10	53,278	88,593.10	69,360	80,182.50	1,381,921.20
Vietnam	16,599.90	767,180.90	33,133.10	88,716.40	65,692.90	81,828	1,147,705.30
Pakistan	87,500	310,990	182,564.90	110,516.50	52,479.00	84,407	309,309.70
Myanmar	57,475	41,820	166,700.60	57,841.40	3,790	3,830	141,204.00
Japan	72.10	0.2	90.00	0.30	230.30	56.10	61.50
China	2,419.00	227.7	24.30	23.80	42.60	6.00	7.00
Others	4.30	6.5	744.60	0.30	760.10	364	12,933.30
Total	305,224.80	2,253,824.40	444,508.80	356,286.20	407,741.40	429,207.30	3,062,857.70

Source: Badan Pusat Statistik (2023)

According to United States Department of Agriculture (USDA) data, Indonesia's milled rice import volume reached 3.5 million tons in 2023. Indonesia's rice imports in 2024 will likely increase again due to an additional rice import quota of 1.6 million tons from the initial quota of 2 million tons (June–April 2024) (Muhamad, 2024). Milled rice imports are listed in **Table 2**.

Table 2. Milled rice import 2024.

No	Country	Volume (ton)
1	Philippine	3,900,000
2	Indonesia	3,500,000
3	China	2,597,000
4	European Union	2,250,000
5	Nigeria	2,000,000
6	Iraq	1,845,000
7	Vietnam	1,800,000
8	Saudi Arabia	1,500,000
9	United State	1,360,000
10	Malaysia	1,350,000

Source: United States Department of Agriculture (USDA), 2023

The government carried out these imports to ensure sufficient domestic rice supplies and prevent inflation due to dwindling domestic rice supplies. El Nio storm caused a long drought, and India, a rice-producing country, stopped exporting rice to Indonesia (Harini & Susilo, 2017). Many countries rely on imports to satisfy their demand for certain food products. To secure access to enough quality foods, people need to have financial means to afford the cost of food at the market. Worldwide prices have a more significant impact on the retail prices of imports. In addition, there are political factors and market psychology (Sundiman & Septiani, 2017). Due to this, the rice supply is dwindling, and the price is soaring (Sholikhah & Anjani, 2023).

Indonesia collaborates with other nations to guarantee a stable food supply. The country has worked with India on several projects over the past two years. One of these projects is the Joint Statement of ASEAN Leaders on Strengthening Cooperation in Food Security during Crises (2023), which will be approved at the next ASEAN-India Summit (ASEAN, 2023a). Through food trade with India, the Indonesian government hopes to guarantee food availability, affordability, and accessibility during times of crisis (Zou & Fan, 2022). Furthermore, by boosting trade in high-quality agricultural and agrifood commodities, Canada can play a significant role as a dependable partner for ASEAN food security, according to the ASEAN-Canada Post Ministerial Conference (PMC) statement (ASEAN, 2023b). The Joint Commission on Bilateral Cooperation (JCBC), which unites Vietnam and Indonesia, is the final one. The goal of bilateral commerce between Vietnam and Indonesia has been raised from the initial goal of at least USD 15 billion in the same year to USD 18 billion or more by 2028 (Ministry of Foreign Affairs, 2024).

Indonesia's agricultural sector is exacerbated by three major factors: the shift in agricultural land use, human resources, and inputs. Rozaki (2021) describes the agricultural challenges in Indonesia as insufficient arable land, increasing farming costs, lack of automation and mechanization, low human resources, and farmers' welfare (Greenpeace Indonesia, 2022; Rozaki, 2021). According to Statistics

Indonesia, the national rice and corn production decreased from 2021-2023 by nearly 1.40% and 10.61%, respectively (Saputra et al., 2022), which eventually led to dependency on copious amounts of imported produce.

Population pressure and urban expansion have reduced agricultural land in Indonesia. The Ministry of Agriculture recorded that cropland in Indonesia decreased by 287,000 ha from 2013 to 2019, with only 7.64 million remaining (Gandharum et al., 2022). Land conversion became inevitable as the population was constantly growing. Nevertheless, it became a substantial threat when land conversion in urban areas and food demand rose strikingly high, and its balance with the food supplies appeared out of control and shrank significantly due to insufficient agricultural land.

Consequently, this resulted in the expansion of agricultural land to the outer islands of Indonesia, which was reported to exhibit low productivity due to the mismanagement of the irrigation system and the low productivity of monoculture plantations that threatened natural resources and altered soil fertility and water scarcity. As a result, Indonesia’s outer regions are experiencing a crucial food scarcity as high-productivity products are mainly concentrated in Java (Badan Ketahanan Pangan Kementerian Pertanian, 2020; Greenpeace Indonesia, 2022). If this continues, the rural areas in Indonesia could suffer from food security in the long term, which could be aggravated by the multitudes of poverty in Indonesia, which accounted for around 9.63% of the population (Ma’ruf Amin, 2024), and the degrading natural resources and low educational level of its human resources in Indonesia’s impoverished regions. This situation could be deemed contradictory to the primary definition of food security as described in the World Food Summit 1996 (Samuels, 1996), which highlighted the inclusivity of food security by acknowledging equal access to food and is often recognized as the core interpretation of food security. Given the reality of the food supply imbalance in rural areas in Indonesia, it is reasonable to propose that immediate actions be taken to generate food stability and accessibility in the country, as the republic’s agricultural state is also struggling with human resources and farming input issues.

Indonesia is also struggling with the availability and quality of farming human resources. The imbalance between agricultural input and output, the aging generation of farmers, and the need for agricultural management education for farmers have intensified the situation. In 2023, Statistics Indonesia reported that the farmers’ population was merely 27.5 million people (BPS, 2011). This data implies the massive disparity between farmers, civilians, and their association as producers and consumers. The disproportional ratio might be obscure as the high population growth in Indonesia overshadowed it. However, as demonstrated by World Bank statistics, the rural population in Indonesia is declining annually and is significantly lower than in urban areas (World Bank, 2012)

Farmers’ reliance on subsidized and nonsubsidized seeds, fertilizers, and pesticides as agricultural inputs to improve crop productivity and quality has also backfired in terms of financial and environmental costs. Farmers struggle with the scarcity and expensive price of new seeds and fertilizers (Rozaki, 2021). The complex regulations and bureau procedures to purchase subsidized fertilizers aggravated the circumstances. The Ministry of Agriculture 2021 set high retail prices for subsidized fertilizers, requiring farmers to be registered for the Farmer Card (Indonesian: Kartu Tani) to purchase them (Badan Ketahanan Pangan Kementerian Pertanian, 2020), which exacerbated the agricultural scenery in Indonesia. These issues could be rooted in the lack of availability and accessibility of farming supplies and their inefficient use, which resulted in economic loss and ecological disruption.

Given the complexity of Indonesia’s agricultural issues, agricultural biotechnology, which offers extensive food and crop production, could be a highly beneficial solution to alleviate these issues. The range of challenges addressed by agri-biotech is not limited to resolving food inadequacy and automation issues but also highlighting the sustainability to promote environmental conservation by reducing waste, maintaining farming resources, and raising agricultural resilience for future use (Das et al., 2023). However, agricultural biotechnology applications in Indonesia are massively challenged by the tedious research progress due to the lack of funding, proper facilitations, and nuanced bureaucracy (Wasilah et al., 2019). Nonetheless, the sector exhibits promising outcomes for present and prospective agricultural practices and has been extensively applied globally, including by developing nations.

This essay highlights the technologies globally adopted to address agricultural and climate change challenges and improve food security. We assessed the achievability of these techniques by analyzing the gravity of Indonesia's geographical landscape, politics, and socioeconomic situation by comparing its agricultural practices to those of tropical and developing countries with similar food security situations to Indonesia. We employed the systematic literature review approach on 23 publications to define the validity of scientific evidence for the research questions. The main objective of this framework relies on formulating appropriate solutions to food security issues by identifying various perspectives related to the topics. This research aims to illustrate technoscientific recommendations for integrating intelligent agriculture practices through biotechnology and forecast its potential implementation in Indonesia.

2. Literature Review

Rising food prices are another reason for food insecurity. A decline in the number of commodities increases the demand for goods and their prices (Sohel et al., 2022). Food supply issues have become increasingly problematic, directly affecting household food security (Nature Plants, 2020). The Indonesian government's pursuit of food sovereignty extends beyond reliance on imported produce to encompass the adoption of agricultural biotechnology practices (Trauger, 2015). This branch of biotechnology could be the solution tightly linked to the intricate nature of food security, climate change, and agriculture (Tyczewska et al., 2023). Regardless of the noble effort to ensure an adequate food supply for everyone, agricultural practices for food production are contributing massively to greenhouse gas emissions due to inefficient farm techniques and the higher rate of crop failure in the aftermath of climate change (Fanzo et al., 2022). Reversibly, the continual effort to raise crop productivity is counterproductive, rapidly exacerbates climate change, and suppresses crop yield by 50-80% due to the biotic and abiotic stress as part of the climate change consequences (Shea, 2008).

Integrating biotechnology into farming was applied in various ways in multiple governorship eras. In 1985, the New Order regime initiated agri-biotech in Indonesia to encourage food self-sufficiency (Khanif & Yunita, 2024). With the primary goal of elevating rice production as the nation's staple food, Suharto's strategies aimed to ally with research institutes, universities, and private-sector investments in accelerating biotechnology research and public campaigns by transforming nearly 1 million forest lands in Borneo into paddy fields through the infamous "Mega Rice" project (Tirtalistyani et al., 2022). In agreement with its predecessor, Yudhoyono's sovereignty also implemented biotechnology to raise farmers' income, as this strategy requires less production costs with higher output and promotes research and development of agri-biotech (Hall, 2023). The latter was documented in the Cartagena Protocol 2004 (Falck-Zepeda, 2009). However, the agricultural policies in both regimes faced significant challenges and criticism from farm stakeholders and the general public. Generally, these constraints could be classified into biophysical and socioeconomic impacts. The biophysical perturbations comprise ecological damage due to the penetration of agricultural land into forest areas like Borneo and Papua in both eras, reduced agrarian diversity, and the loss of flora and fauna in several assigned areas (Khanif & Yunita, 2024).

On the other hand, the socioeconomic impacts of the policy, which consist of land ownership, ethical issues regarding indigenous land eviction, and farmers' welfare infringement, have gained criticism from experts and activists (Onwe et al., 2023). Regardless of the frequent failures in delivering food security and sustainable agriculture through legal practices, the Indonesian government's ultimate agenda to actualize food independence remains unwavering. This statement is demonstrated by establishing the Food Estates program in Widodo's era (Rozaki, 2020). The Food Estate (FE) program, launched as part of Widodo's governorship master plan from 2020–2024, will cultivate various staple crops to ensure food adequacy. In Central Kalimantan, South Sumatra, North Sumatra, and East Nusa Tenggara, Food Estate development has already begun (Lasminingrat & Efriza, 2020). Previously, the FE policy was implemented by state-owned enterprises, namely PT Wijaya Karya and PT Pembangunan Perumahan in Kuala Kapuas Regency, Central Kalimantan (Fadillah et al., 2021). For now, the FE policy is implemented by involving the community. During this program, the company prepares canals, irrigation construction, and rice field design. The phenomenon of the COVID-19 pandemic shows the existence of non-conventional threats to national security when restrictions occur. Therefore, the government could deem food estate the right strategy (Ito et al., 2014)

As a large-scale program, FE uses capital, technology, and other resources to produce food sustainably. The FE development target in Central Kalimantan is 30,000 ha, with 10,000 ha in Pulang Pisau District and 20,000 ha in Kapuas District (Mukti, 2020). The project reused an earlier zone from the PLG (peatland development) in Kalimantan (Surahman et al., 2018), which was deemed unsuccessful and abandoned in 1995 but then discontinued in 1999 (Goldstein, 2016; Kwasek, 2012). This peatland zone was designed to produce large-scale rice paddies. However, peatlands' preparation and spatial planning for large-scale rice paddies violated ecological principles. As a result of unplanned canalization, the peatland became rapidly drained and degraded, making it highly susceptible to fire. As large-scale food estate development is perceived to ignore issues such as social conflict, deforestation, biodiversity loss, and pressure on surrounding communities, FE programs on peatlands have many pros and cons (Eryan et al., 2020; Setyo & Elly, 2018). The level of risk for running a food estate on peatland is moderate to high. Five sources of risk are considered most at risk of impact based on the risk source analysis. They are human activities, rice development in farmers, free-range animal species, farming methods and communities, and changes in farming practices. As a natural resource, peatland is highly vulnerable, and mitigation as part of risk management must be done with great care. Moreover, the government's approach to providing input subsidies could be more effective, as beneficiary farmers face technical problems caused by different farm management systems (Yeny et al., 2022). Meanwhile, farmers usually prefer to grow certain crops based on habit rather than government subsidy programs (Ayodeji et al., 2017; Nyagaka et al., 2010).

As a result, Food Estates has gained mixed responses from key agricultural players, the locals, and experts. The lack of multidisciplinary engagement in developing regulations has resulted in harvest failures, mismanagement of resources, and environmental deterioration (Greenpeace Indonesia, 2022). Incorporating inclusive biotechnological strategies to address these biological and socioeconomic challenges in achieving food self-sufficiency is vital. This can be done by involving various agricultural stakeholders, such as farmers, scientists, legal institutions, the private sector, and officials, and considering public aspirations and needs.

More vital collaboration between the government, private sector, international organizations, and research institutions to help farmers is essential to implementing biotechnology in Asia. Adequate resources are another critical component in improving agricultural research and development. To achieve sustainable agriculture in ASEAN, it is crucial to support policies encouraging continued investment in agricultural research and development (Teng & McConville, 2016). Agricultural challenges and food security strategies in tropical countries, especially those classified as developing ones, are similar to those in Indonesia. Given the identical climate and topological profile, it is rational to consider agricultural biotechnology and technical practices in such countries to narrow down its possible implementation in Indonesia regarding the technical, political, and socioeconomic schemes to formulate appropriate suggestions for Indonesia.

Like Indonesia, population explosion, land conversion, and massive industrialization are the epitome of agricultural and food security challenges in tropical and developing countries. For instance, agriculturally sustainable developing and tropical countries like Brazil, which accounted for the fifth-largest population on Earth, have successfully engraved their title as major food exporters (Oliveira et al., 2023). According to the United States Department of Agriculture (USDA) data, the agricultural value in Brazil has skyrocketed around 10% in the past two decades. It has been inscribed as a notable food supplier internationally, surpassing the United States by around 20% (Valdes, 2022). These advancements are tightly correlated to the rapid progress in agricultural biotechnology research and development. International Service for the Acquisition of Agri-Biotech Applications (ISAAA) recorded Brazil as the second most significant biotechnology crop producer. It ranked at the top of biotechnology implementation in developing countries (Foreign Agricultural Service, 2022). Despite climate change, Brazil relies heavily on genetically engineered (GE) crops to supply the massive population. This could root in significant support by increasing arable land areas, vast investments, and authoritative support through efficient framework approval.

GE crops research and development in Indonesia encountered severe challenges. According to the Ministry of Agriculture, the post-monitoring guidelines for GE crops were only issued in 2020, while the regulatory framework was legalized in 2005 (Foreign Agricultural Service, 2021). The long gap between authoritative issuance and monitoring resulted in commercialization resistance, declining public and consumer beliefs, and technological advancements. Culturing crops produced through GE is still debatable due to controversies about its potential advantages and dangers (Ghimire et al., 2023). Moreover, the GE approval framework in Indonesia is required to pass the Islamic halal inspection. Recently, for a GE crop to be available commercially, the product has to surpass the evaluation assay by the Ministry of Agriculture, Food and Drug Supervisory Agency (BPOM), and Institute of Drug, Food, and Cosmetic Studies (LPPOM) by the Indonesia Ulama Council (MUI) (Andoko, 2018), which could result in complex paperwork and administrational process when ensued within three different institutions. However, the Islamic criteria for approval were relatively simple, as stated in the Islamic law of MUI 35/2013, which states that the GE crops must not harm the environment and alter human genetics and must be generated for good cause (Fatwa Majelis Umum Indonesia Nomor: 35 Tahun 2013 Tentang Rekayasa Genetika Dan Produknya, 2013). Nonetheless, the simplified regulatory framework that objectively supervises GE crop research and commercialization must be implemented in Indonesia.

Another fundamental strategy in agricultural biotechnology practices in developing and tropical countries is farming automation. These mechanization strategies include supplementing farming machinery and improving agrarian supplies. A case study in Thailand, which overcame similar issues in industrialization and populational bloom in the 1980s, was resolved successfully by applying both strategies. Recovering from the decline in agricultural performance due to the vast industrialization in the 1980s, the Thai government now focuses on the farming sector's significant investment and technological refinements (Diao et al., 2020). Therefore, instead of importing produce to guarantee the nation’s food security, Thai authorities import agricultural machinery like tractors, sprayers, and water pumps. This scheme has helped the farming sector massively, as the critical Thai agricultural actors are domestic and smallholders of crop farms. Rozaki (2021) argues that machinery supplies in Indonesia would be challenging to distribute as the mountainous cultivation areas are scattered in rural regions (Rozaki, 2021). However, this was not the case in Thailand, where the places are also mountainous and considered rural, and it was proven to be successful in boosting crop productivity and quality. Thus, it is rational to propose that this automation strategy can be applied in Indonesia.

Urban farming is considered a means to tackle the land conversion issue in densely populated countries. In Singapore, whose proportion of metropolitan areas is strikingly high compared to the rural agricultural land, food insufficiency became a severe issue without proper intervention, eventually leading to dependency on imported food products. The adoption of biotechnology practices in Singapore’s urban farming consists of vertical farming and aquaponics (Maryanti et al., 2022; Munir et al., 2022). Vertical farming is defined as cultivation practices in a stacked arrangement while maintaining the growth conditions according to the plant's needs. It was stated that vertical farming has the potential to reduce agricultural inputs and emissions while enhancing productivity by allowing different crops to grow altogether (Al-Chalabi, 2015). Singapore has generated recycled water and lighting management for fruits and vegetables in vertical farming. This technique might be suitable for implementation in urban areas like Java islands.

3. Method

This research uses the systematic literature review (SLR) method. SLR is a method that transparently synthesizes previous scientific evidence to answer research questions (Wang, 2020). Publication qualifications add value to the synthesized scientific evidence (Triandini et al., 2019). SLR identifies, interprets, reviews, and evaluates research in a particular topic area and aims to determine strategies to help address the problem and identify different perspectives related to the issue being researched. In addition, SLR also seeks to reveal the theory relevant to the case in the study (van Dinter et al., 2021). Five steps need to be taken when using the SLR method:

3.1. Defining the Problem

Researchers can uncover problems by examining real and existing difficulties in Indonesia. The current situation is the high number of food imports, which shows that Indonesia's food security is vulnerable and dependent on other countries. Meanwhile, developed and tropical countries have implemented biotechnology as one of the solutions to meet their populations' food needs independently. Therefore, the use of technology must be studied further by considering various conditions in Indonesia, such as political issues, environmental issues, climate change, regulations, and others, as well as their socioeconomic and political impacts. Therefore, the researcher designed this study to answer the following research questions:

- RQ1: How is biotechnology applied in agricultural practices in tropical countries and its feasibility of implementation in Indonesia?
- RQ2: How is agriculture's socioeconomic and political dimension in Indonesia and its implications for biotechnology advancements in Indonesia?
- RQ3: What could be the appropriate solution to overcome the food crisis in Indonesia?

3.2. Data Collection

Researchers collect data from credible data sources by gathering the information through Scopus and Google Scholar. The use of two different data warehouses aims to enrich the data. Scopus is known for its extensive data coverage with many publishers and is the primary source for indexing various quality scientific papers and articles from multiple countries (Jabeen et al., 2021). Scopus is the largest database of abstracts and citations of peer-reviewed literature, with extensive and reliable coverage. In addition, Scopus provides complete data for each reference (Zanjirchi et al., 2019). Scopus's diverse and inclusive nature guarantees the inclusion of new, pertinent, and up-to-date findings and the review of emerging subjects. It also ensures that a vast number and broadened scope of research on sustainable servitization and other related studies are captured (Temouri et al., 2022).

The rationality of using Google Scholar to add data is its consistency in indexing bibliographic data using the International Standard Bibliographic Description (ISBD) as a standard bibliographic description that can be read easily (Fani & Rukmana, 2022). Standard Bibliographic Description (ISBD) is a standardized principle that promotes universal bibliographic control of published articles from various countries. The primary purpose of ISBD is to ensure consistency when sharing bibliographic data and specifying the data elements that should be recorded or transcribed (IFLA, 2007).

After determining the data warehouse to be used, the next step is to determine the keywords relevant to the problem topic. Researchers determined several keywords, including: "Indonesia food security," "policy," "agriculture and biotechnology," "plants abiotic, biotic stress," "climate change," "plant land water conservation," or "genetically modified plant." The selection of keywords began with an initial review of food security issues in Indonesia. Then, another set of words was determined based on the relevance and coverage of the research objectives and research questions compiled previously.

In the Scopus search, the researcher entered keywords in the search field and assigned Boolean operators "AND" and "OR" to each keyword. The Boolean operator "AND" is used to separate keyword group combinations. Meanwhile, the Boolean operator "OR" separates keyword combinations within the same group. In the data search process, almost all keyword words are separated with the Boolean operator "OR" because researchers want to find articles with related keywords. While the Boolean operator "AND" is set on the keyword "policy," this is done because researchers only want to see the keyword "policy" in the same article as other keywords. If the researcher does not provide the "AND" restriction on the keyword "policy," the data will appear in large quantities, and the data tends to be less relevant to the research objectives. The data collection process on Scopus was carried out on June 7, 2024, with restrictions f(Van Eck & Waltman, 2007)or data from 2020-2024 (5 years) and obtained data from as many as 505 documents. Then, the researcher filters through various aspects such as subject area, keywords, language, document type, and publication stage.

Furthermore, the data search through Google Scholar was conducted on June 7, 2024. Researchers used the Publish or Perish application to search for data. The search process was carried out by entering the keywords "Indonesia food security," "policy," "genetically modified plant," "agriculture and biotechnology," "abiotic, biotic stress," "climate change," "land water conservation," in the same search field with restrictions on the year of publication of articles from 2020-2024 and the maximum number of articles is 200. The results of data searches from Google Scholar and Scopus are stored using the RIS format and analyzed through VOSViewer, making it easier for researchers to perform citations with the help of the Mendeley application.

Researchers will analyze the data collected from the Scopus and Google Scholar search results to determine the novelty or gap of the collected keywords. The analysis was carried out using the VOSViewer application. VOSviewer, an open-source software for bibliometric analysis that can analyze large amounts of data and provide excellent network data mapping, has become the main focus. (Bukar et al., 2023). VOSviewer uses the VOS mapping technique. VOS (Visualization of Similarities) is an idea developed less than two decades ago to analyze and visualize patterns in data (van Eck & Waltman, 2007). A few years later, the VOS idea was transformed into a program for bibliometric analysis and has now been widely adopted in bibliometric and citation studies to construct and visualize bibliometric networks, with individual journals, researchers, or publications as actors, based on co-citation, bibliographic merging, or authorship relationships (van Eck & Waltman, 2010).

Based on the data analysis obtained from Scopus and Google Scholar, 7 clusters were produced, as illustrated in **Figure 2**. From a network visualization perspective, it can be concluded that there is quite a lot of research discussing "food safety." this is indicated by the circle size with the keyword "food safety," which is more significant than other keywords. Although, in the data search process, researchers have included the keyword "biotechnology," the analysis results do not show the relationship between "food safety" and "biotechnology." Therefore, research using "food safety" and "biotechnology" has interesting novelty and originality. In addition, to answer the research question, it is expected that there are government regulations that can ensure food safety. The analysis shows that "food safety" also has no relationship with "government policy," so it is appropriate to include it in the research topic.

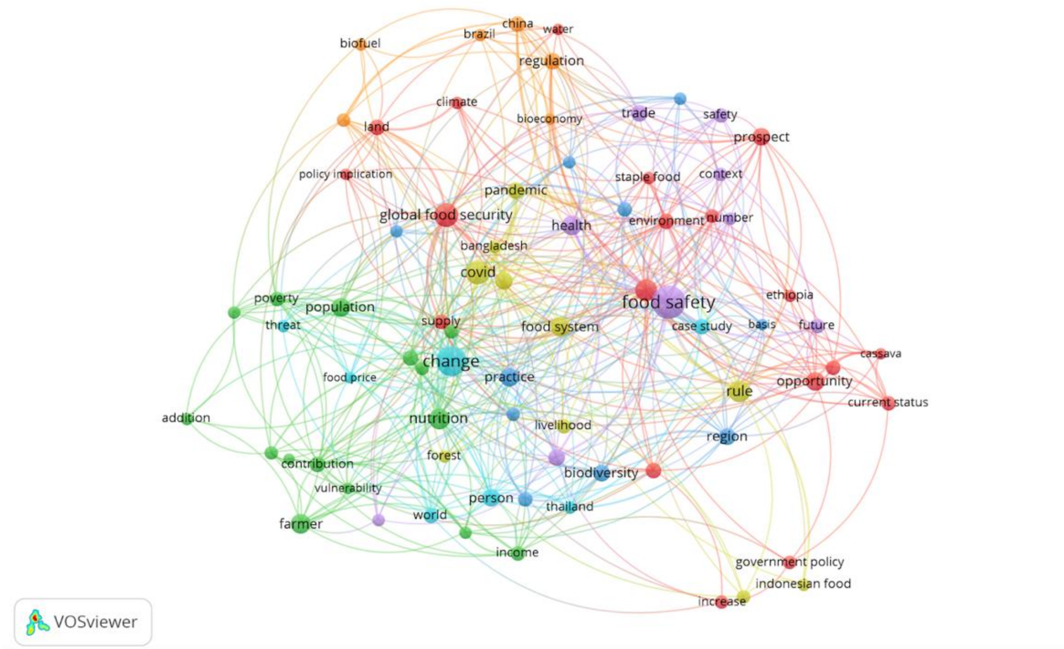

Figure 2. Network visualization mapping. Source: VOSViewer Analysis.

Meanwhile, based on the year of publication of the article, the most research on the topic of "food safety" was published in early 2021, as visualized in **Figure 3**. The latest research from the keywords analyzed by VOSViewer was most recently published in August 2021. So, it is very appropriate to return to research on "food safety" in 2024, which is associated with other variables.

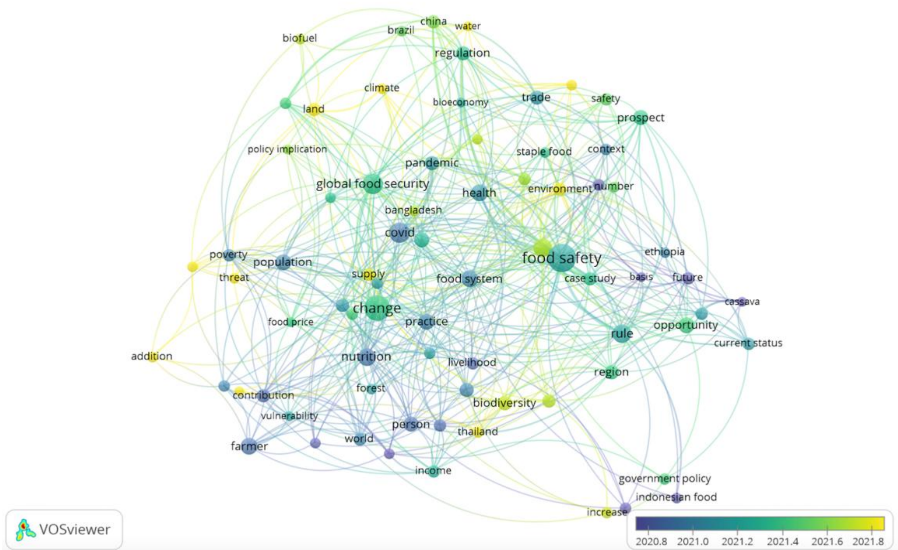

Figure 3. Overlay visualization mapping. Source: VOSViewer Analysis.

3.3. Eligibility Criteria

At this stage, the researcher must search for literature suitable for the research topic. In some studies, this third process is determining eligibility criteria. In this process, the researchers provide limitations based on the inclusion and exclusion criteria. These guidelines demonstrated how to apply limitations when conducting a literature search. Limitations are essential to restrict the number of studies returned by the literature search by date or constraints, which can be used to specify the literature search for particular study designs or other indicators. As limiting the literature search may lead to bias (as discussed above), the use of limits should be explained, and the implications must be investigated. It has been suggested by Craven and Levay (2011) that decisions about the use of search limitations should be captured by using a supporting narrative to explain the decisions made during the development of the literature search (Craven & Levay, 2011). The eligibility criteria are listed in **Table 3** and **Table 4.**

Table 3. Eligibility criteria for Scopus search result.

Item	Inclusion	Exclusion	Rationality
Year	2020-2024	Before 2020	Researchers prioritize recent research
Language	English	Other than English	Research that uses English (an international language) is more eligible.
Paper Access	Open Access	Paper need subscription	Open Access makes it easier for researchers to obtain articles
Type Paper	Article	Book & Proceeding	-
Keyword on Article	"Environment" "Agricultural" "Social Science" "Biochemical"	”Agroforestry," "Livelihood," "West Java," "Urbanization," "Spatial Analysis," "Rural Development," "Rain," "Human," "Government," "Ecosystems," "Central Java," "Article," "Vulnerability," "Smallholder Farmers," "Sea Level," "Livelihoods," "Java," "International Trade," "Integrated Approach," "Income," "Household Income," "The Greater Sunda Islands," "Floods," "East Java," "Coronavirus Disease, "Commerce," "Sanitation," "Rural Area," "Rainfall," "Regression Analysis"	Eliminate less relevant keywords to obtain research with a focus on the topic.
Journal Quartile	Q1, Q2, Q3	Other than Q1, Q2, Q3	Q1-Q3 is considered a journal that has good credibility

Source: Data processing by researchers

Table 4. Eligibility criteria for Google Scholar search results.

Item	Inclusion	Exclusion	Rationality
Year	2020-2024	Before 2020	Researchers prioritize recent research
Language	English	Other than English	Research that uses English (an international language) is more eligible.
Paper Access	Open Access	Paper need subscription	Open Access makes it easier for researchers to obtain articles
Keyword		"Africa," "Biofuel," "Oil palm", "Fish"	Irrelevant to the research topic
Type Paper	Article	Book & Proceeding	-
Journal Quartile	Q1	Other than Q1	Q1 is the top-tier journal category

Source: Data processing by researchers

3.4. Defined Reviewed Literature

After the researcher determines the literature to be reviewed, the next step is to select the literature using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method **(see Figure 4).** The British Medical Journal (BMJ) introduced this method in 2021. The Prisma method is a commonly used bibliometric and SLR analysis guideline. This study used this method. Document identification, screening, eligibility, and inclusion are the four steps PRISMA uses to select published documents from various databases (Echchakoui, 2020).

PRISMA has become the accepted standard in conducting Systematic Literature Reviews. The PRISMA process simplifies objectivity and allows researchers to assess the quality of the review. As the PRISMA process explicitly applies inclusion and exclusion criteria to describe the research question, researchers state that PRISMA suits management-focused themes. In addition, the PRISMA standard enables accurate and efficient research into large databases, which makes detailed investigations easier (Moher et al., 2009).

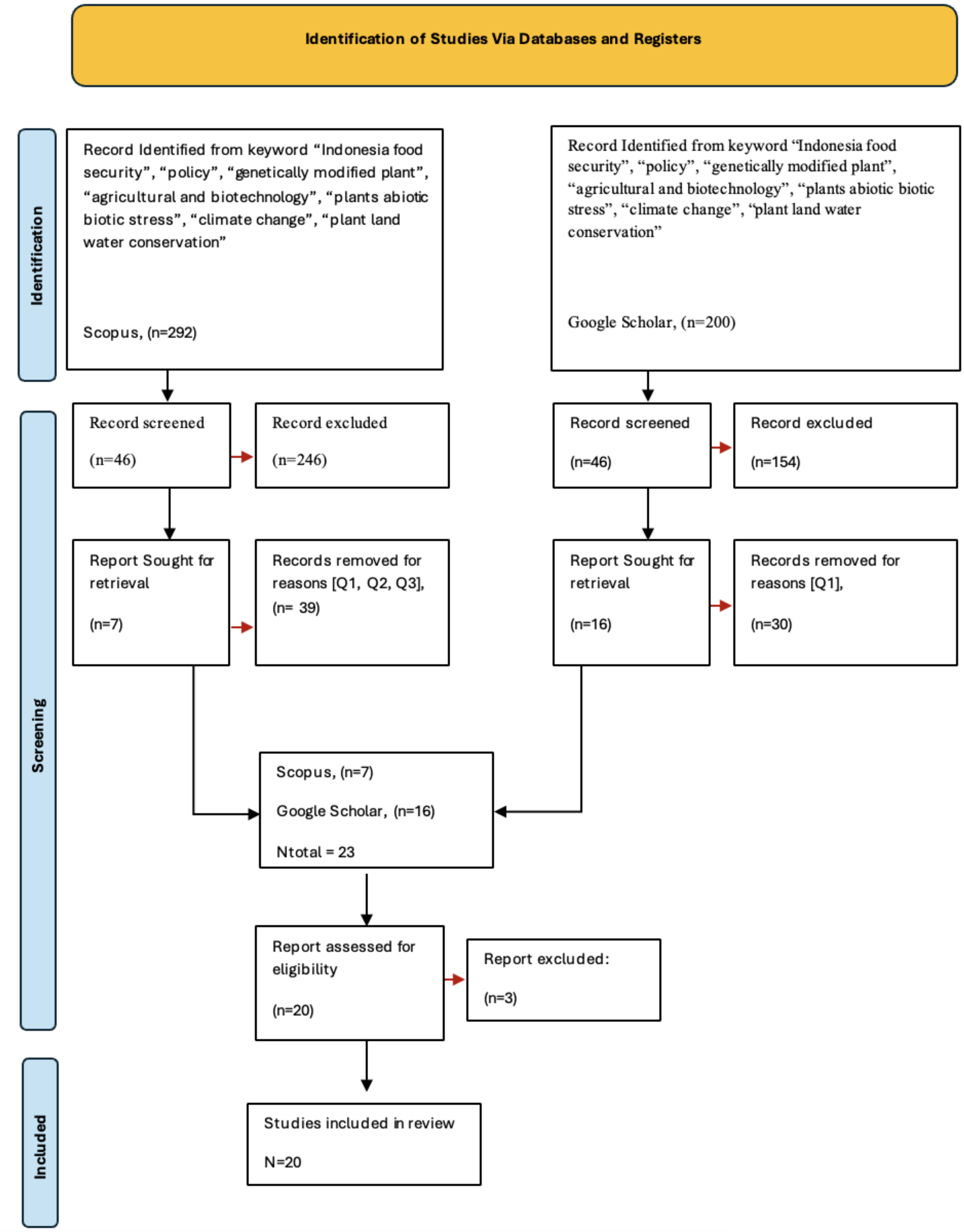

Figure 4. PRISMA chart flow. Source: Data processing by researchers.

The first step in creating a PRISMA diagram is identification. From the results of data searches using keywords related to the research topic, the results obtained from the Scopus database were 292 pieces of literature observed. At the same time, we earned 200 pieces of literature from Google Scholar. Furthermore, the screening process uses limitations based on the eligibility characteristics determined in stage 3. By going through the limitations, there was a reduction in the amount of literature, 246 from Scopus and 154 from Google Scholar. Thus, the remaining literature from the Scopus and Google Scholar search is 46 each.

From the screened literature, researchers confirmed the credibility of each journal through the SCImago Journal Rank (SJR) portal. This platform takes its name from the SCImago Journal Rank (SJR) indicator pdf, which SCImagojr developed from the widely recognized Google Page Rank™ algorithm. This indicator shows the visibility of journals in the Scopus database from 1996 (ScimagoJr, 2024). The reviewed article is listed in **Table 5.**

Table 5. Detailed information of the reviewed article.

Authors	Source	Variable
(Antriyandarti et al., 2024)	Environ. Challenges	Agriculture; climate change; dual role of women; food security; rural Java
(Maryanti et al., 2022)	J. ASEAN Stud.	Desecuritization, food security, food self-sufficiency, securitization
(Ahmad, F., K. Kusumiyati, R.S. Sundari, M.R. Khan, 2023)	Agric.	Food policy; stochastic frontier; strategic commodities; technical efficiency
(Jamaludin et al., 2021)	Univers. J. Agric. Res.	Food Security; rice availability; system dynamics
(Yeny et al., 2022)	Sustain.	Food security; peatland ecosystem; socio-economic; sustainability benefit
(Abdillah et al., 2023)	Cogent Food Agric.	Food security; farming agricultural; systematic literature review; urban farming; urban resilience
(Smith et al., 2020)	Glob. Chang. Biol.	adaptation; adverse side effects; co-benefits; demand management; desertification; food security; land degradation; land management; mitigation; practice; risk management
(Mok et al., 2020)	Trends Food Sci. Technol.	Alternative food sources; Food security; Technology innovations; Urban farming; Zero waste food processing technology
(Savary et al., 2020)	Food Security	Global food security; crises; earth system; environmental footprint; spatial scales; system resilience; time characteristics
(Jiren et al., 2021)	Environmental Management	Institutional interplay; Institutional structure; Integration; Policy incoherence; Policy output
(Chávez-Dulanto et al., 2021)	Food Energy Secur.	Climate change; food security; genetic erosion; integrated pest management; mycotoxins; water-saving agriculture
(Rachman et al., 2022)	PLoS ONE	Sustainability status, sensitive and critical factors for increasing rice production
(Mohidem et al., 2022)	Agriculture (Switzerland)	food security; rice cultivation; rice diversity; rice milling; rice nutrient; rice production
(Gunawan et al., 2022)	Agriecobis J. Agric. Socioecon. Bus.	Farmer economic institution, corporation, regency, East Java
(Albahri et al., 2023)	Agronomy	Effective approaches; essential grains yield; food security; sustainable agriculture
(Selvan et al., 2023)	Frontiers in Sustainable Food Systems	5R-concept; Circular-Organo-Agroforestry; agroforestry; crop biodiversification; lesser-known crops; organo-agroecosystem; sustainability
(Susilawati et al., 2023)	Agronomy	Competitive analysis; economic feasibility; quantitative strategy planning matrix; spatial analysis; tides
(Atkinson & Alibašić, 2023)	Sustainability (Switzerland)	Indonesia; climate change; governance; peatlands; resilience
(Susanti et al., 2024)	Sustainability (Switzerland)	Agroecology; biochar; biofertilizers; climate change; greenhouse gases; inorganic fertilizers; nutrient management; organic matter; paddy field conversion; rice self-sufficiency; stonemeal
(Kliem, 2024)	Environment, Development and Sustainability	Agroecosystems; Commons; Governance; Organic; Philippines; Resilience; Seeds

Source*:* Data processing by researchers

3.5. Data Analysis

After determining the articles to be reviewed, researchers understand the search results summarized at the analysis stage. At this stage, researchers proposed a research conclusion, a brief statement about the results of the description analysis derived from facts or logical relationships, and answers to the arguments raised in the problem formulation section. The whole answer only focuses on the scope of the question, and the amount is adjusted to the formulation of the existing problem.

4. Result and Discussion

4.1. Result

After reviewing the papers, researchers can present some data on the country of origin, year of publication, research source, and subject area of the articles that have been reviewed, along with the analysis described below.

Based on the subject area of the reviewed articles, it can be concluded that most articles discuss food security (57%), as illustrated in **Figure 5**. Meanwhile, the subject-reviewed articles that still relate to the topic of this research are related to sustainability (13%), Agriculture (13%), Farmer Economic Institute (5%), Food Policy (4%), Food Insecurity (4%), and Food Policy (4%).

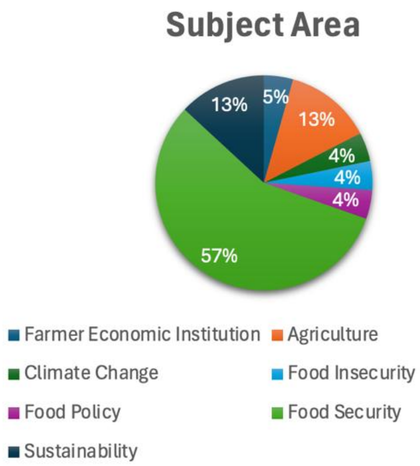

Figure 5. Subject area of reviewed papers. Source: Data processing by researchers.

The articles reviewed were primarily published in 2023, as depicted in **Figure 6**. Meanwhile, articles discussing topics related to this research continue to grow. This shows that academics and researchers are interested in researching food security topics.

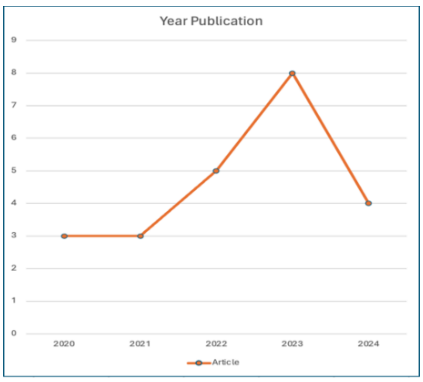

Figure 6. Publication year of reviewed papers. Source: Data processing by researchers

Most articles (journals) come from the Journal of Sustainability (Switzerland), which has three articles listed in **Figure 7**. Sustainability is an international, peer-reviewed, open-access journal on human beings' environmental, cultural, economic, and social sustainability, published semimonthly online by MDPI.

Frontiers in Sustainable Food Systems is a multidisciplinary journal that combines fundamental and practical research to look for sustainable ways to solve the problem of global food security. Meanwhile, Agronomy takes a comprehensive, integrated approach to agriculture. Agronomists are experts in ecology, soil science, and crop science. Crop type is another way to categorize agronomic crops. Numerous agronomists have one or more crop specializations. Then, Agriculture (Switzerland) research on crop and animal production, biosecurity, postharvest handling of produce, agricultural technology, management of the natural resource base for agricultural production (land, soil, and water), rural management and agricultural development, and agriculture in changing environments.

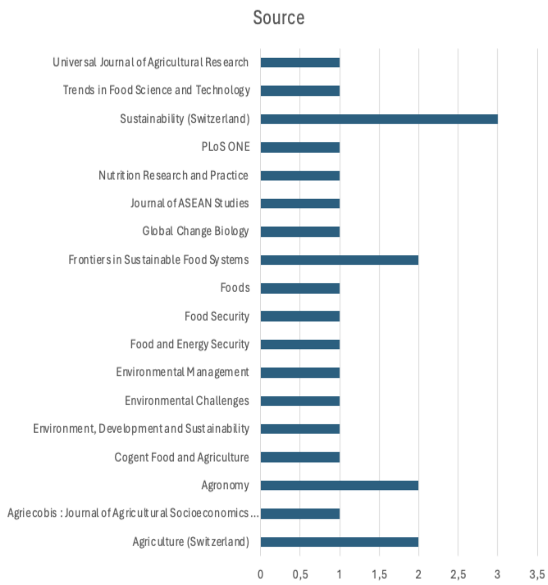

Figure 7. Source of Reviewed Paper. Source: Data processing by researchers.

As seen from the origin of the research country in **Figure 8**, 13 articles were obtained in Indonesia. The results of this classification are hoped to provide an accurate picture of Indonesia's food security problems and efforts to solve them. Meanwhile, articles originating from countries can be used as additional information that makes it possible to provide input or solutions to Indonesia's food security problems. One is Europe, which has long realized the importance of food security and has now implemented it through biotechnology.

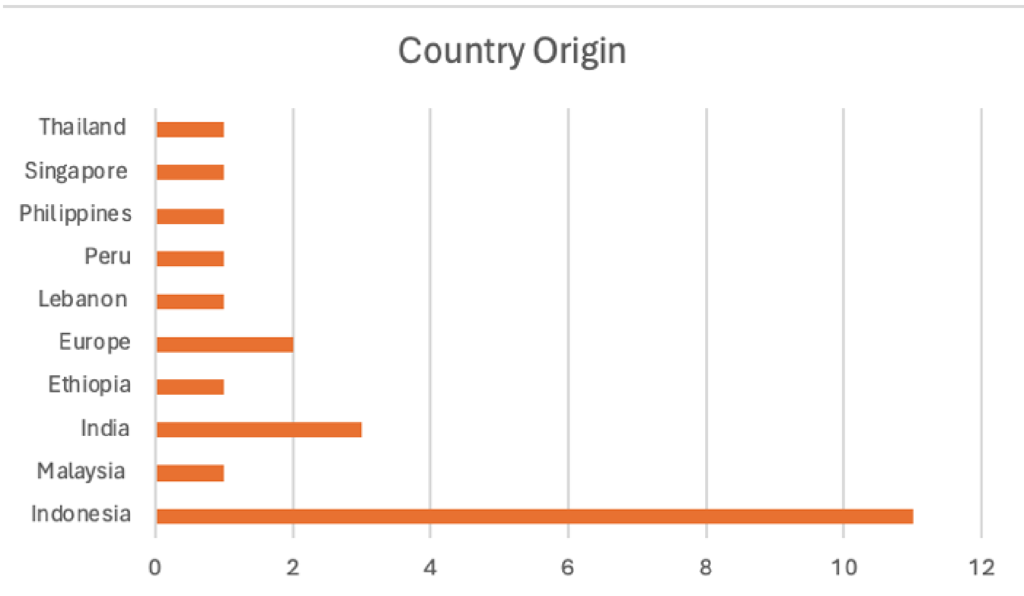

Figure 8. Country origin of the reviewed paper. Source: Data processing by researchers.

4.2. Discussion

4.2.1. Technical feasibility of combined agricultural biotechnology adoption in tropical countries similar to Indonesia for sustainable farming practices

Agriculture is the backbone of civilization. Its merits and drawbacks extend beyond the food it produces and the economy. Of the utmost importance, it consequently affects the environment, the way we live, and, eventually, our future. Therefore, it is only rational to propose the collective effort into the agricultural adaptation of techniques and strategies applied in developing tropical countries that have properly advanced their food adequacy, economy, and ecological conservation to Indonesia. Here, we suggest several approaches with a focus transcending beyond scientific measure and considering agriculture's socioeconomic and political aspects.

Farming, in all its essence, begins from the soil. According to the Ministry of Agriculture, Indonesia strives for agricultural intensification and extensification (Yuliastuti, 2023). The former is performed by increasing yield through fertilizer subsidy, and the latter is engaged by extending agrarian fields to rural areas outside Java, as aforementioned. However, these strategies cost the nation its ecological heritage from deforestation, wildfires, and water resources, which could be summarized as the cause of climate change and aggravated agriculture interchangeably. Here, a stable climate is paramount when engaging in sustainable agricultural practices. Therefore, other alternatives for soil conservation should be initiated by proposing several strategies adopted by various tropical countries worldwide.

Microorganisms, though invisible, are the main cast of soil health. Soil biota is crucial for enhancing crop yield and is now significantly challenged by the introduction of chemical-based fertilizers, pesticides, and fungicides (Romero et al., 2023). Apart from the environmental costs, the intensification effort using these chemicals could result in the degradation of soil microbial communities. Santoyo et al*.* (2022) reported that applying the products mentioned earlier reduced soil nutrient levels, such as phosphorus and nitrogen, and the bacterial community, which was beneficial for enriching biodiversity and enhancing pollination, essential for promoting yield (Santoyo et al., 2021). Therefore, we suggested permaculture as the primary strategy for mitigating soil biodiversity loss.

Permaculture, defined as sustainable agriculture practices emphasizing the natural, resilient, and diverse farming ecosystem, has gained the interest of critical agricultural actors worldwide (Ferguson & Lovell, 2014). First introduced in 1978 by Bill Mollison, permaculture was established under three principles: earth care, people care, and fair share, which we will be concentrating on earth care in this paper (Ferguson & Lovell, 2014). This agriculture niche is oriented toward designing a farming framework that centers on nature by excluding chemicals and carbon emissions, eliminating fossil-fuel-based machinery, and preserving the ecosystem by enhancing biodiversity. Centers on resource maintenance permaculture could be a fruitful solution for the drought and water resources issue in Indonesia's agricultural land. One particular permaculture method that is often used is the permaculture pond. A permaculture pond could be generated by constructing a *swale,* a type of trench between the crop fields, to ensure water circulation through the soil. This trench could be designed by assembling a bunch of logs that act as a water absorption system. These logs are then covered by organic materials like wood chips, using a technique called *mulching.* Thakur and Kumar (2021) reported that organic mulching could boost soil moisture, pest control, and crop yield while reducing the evaporation rate. They also deemed it an opportunity to redesign the physicochemical properties of soil positively (Thakur & Kumar, 2021).

Similarly, in Cambodia, where farmers have been struggling with drought for years, the hydraulic and irrigation framework was modernized by establishing the hierarchy of canals that allows the rivers or reservoirs to flow and pump them into the field (Diepart & Thuon, 2022). This strategy, which the government and stakeholders rallsied, has revolutionized thousands of lives, enabling the farmers' society to improve their yield, quality of life, and profits (Niras, 2023). Moreover, rearranging the irrigation system conserves water resources and minimizes labor-intensive practices.

Other successful permaculture methods are cover crops and crop rotation, which have been used massively in tropical developing countries, where farmers implement these approaches. Cover crops, a group of plants cultivated on the soil surface, can improve crop yield and soil fertility (Adetunji et al., 2020).

Cover crops like peas and oats are essential in shielding staple food crops from extreme weather such as storms and floods, as well as machinery actions like tractors and elevating pest management by secreting antimicrobials (Blanco-Canqui et al., 2015). In Costa Rica, farming practices using cover crops in the natural tropical habitat ensure yield, plant immunity, wildlife conservation, and natural pollination (Webber, 2020). Meanwhile, crop rotation between soybean and corn in Brazil improves soil nutrient levels and physical, chemical, and biological characteristics (Volsi et al., 2022). Research suggested that the diversification using lentils, wheat, and chickpeas has demonstrated a significant increase in abiotic and biotic stress resistance (Li et al., 2019). If applied continuously and responsibly, these techniques can be feasible in Indonesia, which faces similar challenges in disease outbreaks, pest invasion, and extreme weather yet has rich crop biodiversity.

On the other hand, alternative scenarios are instrumental in adapting to the situation in several regions of Indonesia that suffer from floods, monsoons, rising water, and rainfall levels. For instance, in Bangladesh, where monsoons are inevitable and destructive to the previous crop planted in the area, farmers have reverted to the hundreds of years-old technique of initiating floating gardens (New York Times, 2014). The idea behind floating gardens is to build a floating platform for the crop to grow appropriately, using water hyacinth as the leading actor of floating gardens in Bangladesh (Irfanullah et al., 2011). This orthodox method encourages an eco-friendly way to incorporate wetlands that can cultivate fruits and vegetables annually. This technique could be achieved in Indonesia by utilizing wetlands for small-scale farming.

In summary, integrating sustainable farming in Indonesia means balancing highly technical and low-cost farming. Large producers oriented on staple food farming can execute advanced technological agriculture by incorporating collaborative work between farmers, stakeholders, and authorities. To ensure farmers' welfare, contract farming can be offered to secure the harvest value and maintain perpetual production. In the future, agriculture can be revolutionized by engineering conventional farming. For instance, multispectral and infrared drones for precise agriculture can detect crop suitability in particular land, examining soil and health (Hafeez et al., 2023). Moreover, designed robots also help farmers determine the dosage of fertilizers correctly to prevent inefficient nitrogen use, while digital soil sensors gather the information for monitoring the soil nutrient levels. (Ghafar et al., 2023; Wu et al., 2023)

Nevertheless, these approaches are only attainable with generous funding, an efficient regulatory model, and proper guidelines for farmers. Alternatively, support from domestic farming, from minor to medium, is mandatory to maximize food security by implementing urban farming in densely-populated areas using feasible methods like aquaponics. With simultaneous endeavors from the public, government, private sectors, and farmers, technical adoptions for agricultural biotechnology are plausible.

4.2.2. Socioeconomic and political dimension of agricultural biotechnology development in Indonesia

Several papers reviewed indicated multidimensional issues in Indonesia's agriculture. The impediments varied from a lack of technical and funding support to regulatory affairs disputes. These constraints are part of Indonesia's multifaceted agricultural biotechnology implementations and ultimately affect the socioeconomic and political dynamics of the sector. Therefore, it is logical to dissect these predicaments and their implications for the applications of agri-biotech in Indonesia.

Regarding technological progression in Indonesia's agriculture, empirical analysis of farming technique advancements dominates the spotlight, particularly in rice cultivation. Notable research by Mohidem et al. (2022) and Jamaludin et al. (2021) highlighted the practical approach to refining rice processing and nutritional content, while the latter investigated rice productivity and consumption in the sociopolitical context (Jamaludin et al., 2021; Mohidem et al., 2022). The bottom line of this research identified that apart from food shortage, the gravity of Indonesia's rice production scheme is intrigued by the paddy storing issue, which is crucial but taken less seriously by agricultural stakeholders, hence threatening rice availability across the nation alternately. Research by Mohidem et al. (2022) proposed advanced technology to combat the storage issue while stressing the lack of budget for implementation (Mohidem et al., 2022). On the other hand, rice availability influenced the striking price of rice, economic stability, and the imbalance between supply and demand (Jamaludin et al., 2021). These studies revealed the implications of funding and governance, which ultimately disrupt the nation's food availability. Thus, it is rational to suggest the significance of adequate research expenditures and the rejuvenation of the policy model to support agri-biotech progression in Indonesia.

Concerning the scope of scientific research, urban farming is one of the rising themes that has garnered significant attention from researchers globally. Abdillah et al. (2023) discovered a growing interest in Indonesia's urban farming research internationally (Abdillah et al., 2023). However, instead of the application of urban farming in Indonesia, correlative problems like poverty, pollution, and ecological concerns motivated the research. This could be due to the lack of actualization of urban agriculture in Indonesia, as the situation is also intensified by COVID-19, as reported by Kang et al. (2024), experienced by fellow ASEAN countries. In response, another paper by Mok et al. (2020) emphasizes the applications of urban farming in Singapore (Mok et al., 2020), which might suit Indonesia's urban demography. Therefore, despite the escalating trend of urban agriculture, a massive research gap in implementing this topic in Indonesia is undeniable. Again, this could be due to the lack of financing to support the research, but it could also be traced back to the lack of public interest, as urban farming might be perceived as the modern solution to food scarcity. Therefore, we argue that despite focusing on the problem surrounding urban farming, researchers could propose practical ways for the public to engage in urban farming. With appropriate education for domestic farmers, the extensification of this technique is attainable as it can draw young farmers to adopt the method.

Beyond the biophysical consequences, climate change also indirectly evoked the socioeconomic elements in Indonesia's agriculture. Antriyandarti et al. (2024) have immaculately documented the impact of climate change on food security and agriculture on rural Java's socioeconomic status. In this paper, they highlighted the exacerbating agricultural challenges experienced by family-based farming practices, particularly by women, and how it stimulated a massive burden in decreasing food availability, family nutritional input, and economic access to food since the farmers are highly dependent on harvest (Antriyandarti et al., 2024). Interestingly, the result of the study pinpointed that poverty and low education are the main culprits of this situation. Consequently, this resulted in no appropriate actions to respond to climate change, as farmers lacked knowledge and education about the issue. Therefore, it is rational to justify that apart from educating farmers, serious efforts, whether politically or ecologically, must be engaged by institutions, authorities, and stakeholders in Indonesia in adaptation to climate change, as Indonesia's policies regarding this threat are limited to air pollution and establishing renewable energy alternatives (Ministry of Environment and Forestry, 2023).

4.2.3. Suggestions for food crisis In Indonesia

In this discussion, we will outline the suggested actions that the government can implement to reduce Indonesia's reliance on food imports. This is related to sustainable food security that can be utilized in the long term.

4.2.3.1. Non-material infrastructure support

The government must also build non-material infrastructure to support sustainable agriculture, enabling durable production, quality products, appropriate farmer income, and professional growth. Public extension services, consultancy, and professional training should be strengthened and improved to (1) provide better professional training, (2) enable access to technology and facilitate decision-making, and (3) minimize the negative external impacts of agriculture, especially pesticide and fertilizer effects, while (4) maximize the positive environmental impacts of agriculture, such as soil protection, carbon sequestration, and biodiversity protection (Savary et al., 2020).

4.2.3.2. Agricultural research investment

Agricultural research always has a high return on investment; hence, government and private sector organizations should prioritize allocating resources for agricultural research (Pemsl et al., 2022). The government must allocate a budget to research biotechnology and produce seed varieties resistant to climate change and pests. The government must ensure access to quality seeds following the needs and practices of farmers and consumers at all times, especially in times of crisis when rice prices have increased. Genetic diversity and genetic resources are central to the ability of agrosystems to adapt to crises and climate change (Savary et al., 2020). The government can cooperate bilaterally with tropical countries with high rice production compared to their food demands such as Cambodia, Brazil, Costa Rica, India, Thailand, etc. Cooperation can take the form of knowledge transfer and agricultural technology application. It was explained earlier, Cambodia can survive the dry season by building a hierarchy of canals that allow rivers or reservoirs to flow and pump them into the fields and proven to be able to increase agricultural production so that it can meet the food needs of its people (Diepart & Thuon, 2022). Meanwhile, in overcoming drought, Bangladesh innovated by creating floating gardens which have also been applied by Myanmar, China and Thailand (Irfanullah et al., 2011). This technique suits areas with tidal land conditions or those that often experience droughts and floods. In Brazil and Costa Rica, crop rotation by diversifying the planting of lentils, wheat, and chickpeas has demonstrated a significant increase in abiotic and biotic stress resistance (Volsi et al., 2022; Webber, 2020).

4.2.3.3. Authoritative engagement with key agricultural actors

The government should encourage farmer association formation, which will help farmers get better information and access the latest technologies to increase their yields (Purnamasari et al., 2023). One of them is the optimization of the Farmer Economic Institution (KEP) program, which should be encouraged by the local government. Being a member of a farmer association significantly increases farmer productivity. Local governments must reactivate farmer groups through KEP, and then, from the formed KEP, the government needs to determine production targets by considering the amount of land area. Through KEP, farmers will receive counselling related to agricultural education and intensive training in dealing with agricultural problems such as climate change and pests. Supervision from the local government is needed for the KEP program to run effectively and efficiently. The local government can order sub-district officials to form a KEP consisting of various farmer associations in each village. KEP must have a program and work target in each sub-district, which are then reported to the local government, c.q., Dinas Pertanian. As previously mentioned, climate change poses a significant challenge to Indonesian agriculture, necessitating specific techniques to ensure its survival. Providing education to farmers through farmer associations is one possible step. Several studies showed that education increases the probability of farmers using strategies to cope with climate change. More educated farmers are more confident, creative, and successful in achieving high yields and a higher return on investment as they understand the latest agricultural innovations and technologies. More educated farmers also adopt new farming methods and technologies, such as new crop varieties, drones for pesticide and fertilizer application, laser land levelers, and so on (Touch et al., 2023).

4.2.3.4. Agricultural subsidiary management

In connection with the ineffectiveness of fertilizer subsidies previously described in Purnamasari's research (2023), fertilizer subsidies are provided as price subsidies funded by the state budget (Purnamasari et al., 2023). **Table 6** shows Indonesia's State Budget allocated for subsidized fertilizer.

Table 6. Indonesia's State Budget allocated for subsidized fertilizer (trillion).

2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
18,4	16,3	13,9	17,6	21	31,3	26,8
2017	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
28,8	33,6	34,3	31,1	27,1	25,2	54

Source: databoks.com

According to the data in the table above, the budget for subsidized fertilizer allocations decreased from 2021 to 2023. This is due to budget savings due to the impact of COVID-19. In 2023, many parties urged the government to increase fertilizer subsidies, which were subsequently realized in 2024. The Indonesian government expects the provision of subsidies through fertilizers to help farmers increase agricultural production. However, subsidized fertilizers are misappropriated every year, as subsidized fertilizers are not distributed according to the target. As a result, farmers need help to obtain subsidized fertilizers from the government (Fahri et al., 2023).

Therefore, to reduce the amount of misappropriation that is increasing every year, it is necessary to shift the formation of subsidies that were previously given in the form of fertilizers. Providing modern technology-based agricultural facilities and infrastructure to support effective and efficient production can offer subsidies. The government can remove the fertilizer subsidy and replace the budget allocation with investment in modern agricultural equipment based on automation to increase rural production effectively and efficiently. In addition, the availability of effective and efficient technology can improve the interest of human resources with productive age to become modern farmers.

4.2.3.5. Optimizing Indonesian National Army (TNI)

According to the Law of the Republic of Indonesia Number 34 of 2004, Article 8, one of the Army's tasks is "to carry out defense empowerment on land." In carrying out this task, the Army dedicates all its efforts, work, activities, and actions to developing its territory. The TNI AD is firmly committed to assisting the government in carrying out its main tasks, especially military operations other than war. This perspective underscores the urgency of the Army's role in assisting the government in achieving food and energy security (SESKOAD, 2015). As we know, farming without the aid of technology is a difficult task. Therefore, the number of farmers in Indonesia is declining year by year. **Table 7** shows the number of farmers in Indonesia.

Table 7. Farmers statistics in Indonesia 2013 and 2023.

Year	Number of farmers
2013	31.715.486
2023	29.360.833

Source: Badan Pusat Statistik, 2023

As observed in the data above, there was a decrease in the number of farmers reaching 7.4%. The lack of education and technology, high agricultural costs, and increased demands forced farmers who do not own land to have no other choice but to work outside the agricultural sector (Anandita & Patria, 2017). Therefore, it is hoped that the Army can cover the needs of the number of farmers and help farmers produce rice to increase rice production, realize food security and reduce the number of rice imports.

4.2.3.6. Annual social assistance budget planning

The Indonesian government always allocates the state budget for social assistance every year. The Indonesia Smart Programme (PIP), the National Health Insurance Programme (JKN-KIS), the Family Hope Programme (PKH), and Rastra Social Assistance/Non-Cash Food Assistance are some examples of social assistance programs for the people. The government provides Prosperous Rice Social Assistance to Beneficiary Families (KPM), providing them with medium-quality rice, up to ten kilograms per month (Kominfo, 2024). **Figure 9** shows The Social Assistance Budget in Indonesia's State Budget 2014-2024.

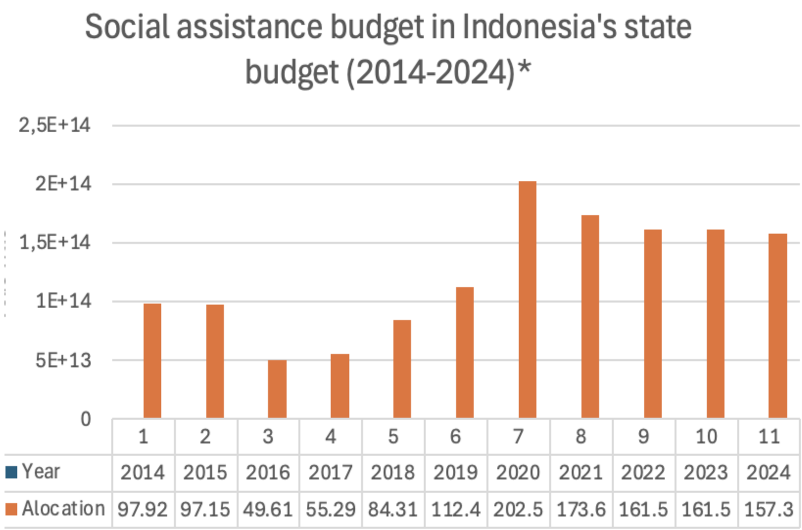

Figure 9. The social assistance budget in Indonesia's State Budget 2014-2024. Source: Adi Ahdiat, Anggaran Bansos dalam APBN Indonesia (2014-2024).

According to the figure above, the highest social assistance budget occurred in 2020, which amounted to IDR 202.5 trillion. This was the government's effort to provide assistance to the community during the COVID-19 pandemic. After some time, the budget for social assistance began to slowly decline. However, in 2024, the social assistance budget was still relatively high compared to the year before the COVID-19 pandemic occurred. In 2024, the budget allocation for social assistance reached Rp157.3 trillion. However, the distribution of social assistance every year is consistently off target. Suharso Monoarfa (Minister of

National Development Planning/National Development Planning Agency of the Republic of Indonesia) said that as many as 46% of social assistance recipients were off target. This is due to exclusion and inclusion errors, hence people who are in need could not get social assistance (Ahdiat, 2024). Therefore, to reduce losses due to the distribution of off-target social assistance, especially social assistance provided in the form of rice, the government can divert the budget for rice social assistance to Bulog by providing subsidy funds to absorb rice from farmers. On the other hand, Bulog, as a state-owned enterprise, still needs help receiving rice from farmers. **Figure 10** shows Bulog's rice absorption in 2019–2023* (November 2023). In the last 5 years, 2023 had the lowest price absorption. In addition to the decline in rice production due to the El Nino phenomenon, Bulog's low rice absorption is due to the low government purchase price (HPP) for unhulled rice, which is set at IDR 5,000/kilogram for the procurement of rice for PSO (public service obligation) needs. Meanwhile, the market price of unhulled rice has reached Rp6,700–Rp7,000/kilogram (as of March 2024). As a result, farmers prefer to sell their grain to the private sector rather than to the government (Bulog). Therefore, given the food crisis and the tendency for private parties to monopolize prices, the government must be able to compete with the private sector by offering a high purchase price for farmers' rice. So that Bulog can absorb rice from farmers and have rice reserves that can meet the food needs of the Indonesian people and can stabilize rice prices when rice prices experience price fluctuations.

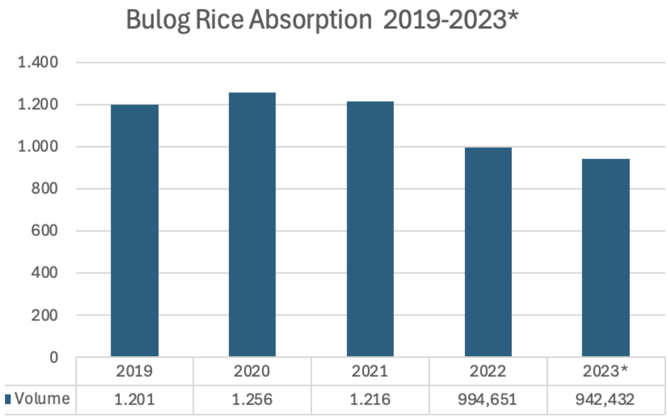

Figure 10. Bulog's rice absorption in 2019–2023* (November 2023). Source: Bulog, 2023.

5. Conclusion

The high number of staple food imports exemplifies the food crisis in Indonesia. Rice, Indonesians' staple food, was imported around 3 million tons, marking the highest import in the last seven years, as recorded by Statistics Indonesia in 2023. Whereas in 2024, Indonesia plans to import up to 3.5 million tons of rice. Indonesia's high number of rice imports will significantly impact the State Budget (APBN) and worsen the national economic burden. This shows that Indonesia has not been able to fulfil the food needs of its people, as it is against the authoritative duty to ensure food availability, affordability, and accessibility for civilians.

The ecological consequences of climate change and population growth also exacerbate the multifaceted challenges. Agricultural input efficiency and effectiveness are the main points for agrarian reform. Thus, strategic interventions through technical and regulatory affairs must be implemented. Key technoscientific strategies could be the appropriate antidotes to the situation, including the advancements of permaculture research and development, agricultural mechanization, and urban farming adopted from developing and tropical countries through agri-biotech. This could lead to higher crop productivity and quality, faster harvest, and increased profits.

In addition, the government needs to reactivate KEP as a forum for educating farmers on managing more productive, effective, and efficient agricultural land. Meanwhile, to increase efficiency and effectiveness in production, the government should change the allocation of agricultural subsidies (seeds and fertilizers) to gradually invest in agricultural machinery by prioritizing areas with more significant land. Food security is an essential priority for the nation. When the country cannot provide its basic needs to the community, the state's role will be replaced by other countries we cannot control.

Meanwhile, the Indonesian government allocates funds for fertilizer subsidies and social assistance subsidies in a form that is often considered untargeted. This approach is highly detrimental to the state as it fails to benefit the impoverished individuals who require it. Therefore, to reduce state losses, the allocation of subsidies for fertilizers can be allocated in the form of infrastructure procurement in the form of agricultural technology that is expected to increase rice production effectively and efficiently. In addition, the rice social assistance subsidy can be diverted by providing subsidies to Bulog so that it can have flexibility in the HPP adjusted to the market purchase price. It is hoped that with grain price competition with the private sector, Bulog can absorb grain from farmers more optimally and have rice reserves that can be sold to the public at low prices when there are fluctuations in rice prices.

Besides that, in connection with the reduced workforce in the agricultural sector, the government can fill the shortage by optimizing the role of the Army to assist in the management and processing of the agricultural sector in accordance with the duties and functions of the TNI in realizing defense in the land territorial area.

The efforts to achieve food security are not straightforward, there are a lot of political interests, as well as social and economic challenges that can disrupt the implementation of food security, Therefore, there is a need for assertiveness from the government to take strategic act to realizing food security and reduce the number of food imports on other countries.

6. Limitations and Future Recommendations

The authors realize that this research suffers from some limitations. This research has reviewed 20 articles, which could be considered a small sample size and may only partially represent part of the range of agricultural biotechnology methods and their effects on food security and climate change. To give a deeper understanding of agricultural biotechnology practices worldwide, future research should broaden the scope of the literature review by adding additional article sources or expanding the year's range. Future studies are anticipated to examine novel and developing agricultural technologies and how they might be incorporated into current methods to boost sustainability and production. Therefore, the research must pinpoint the specific impacts of various climate change scenarios on Indonesian agriculture and develop appropriate biotechnological solutions to alleviate these impacts. Research on the socio-economic effects of switching agricultural input subsidies from conventional to cutting-edge technology is also necessary, focusing on small farmers.

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