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Review Paper

Revealing Food Fulfillment Threads and Innovative Technology for Enhancing Rice Productivity and Ensuring the Food Security in Indonesia

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***Abstract*—Ensuring food security by Indonesia's Golden Year in 2045 presents a formidable challenge, with advancements in agricultural technology anticipated to play a crucial role in attaining this goal. Rice is the major food crop in Indonesia, and its consumption is still considerably high, indicating that daily nutrient uptake relies on its grain. However, the current population of Indonesia demanding rice is 31.2 million tons and this number of populations will grow at the rate of 0.41 percent. The rice consumption of the Indonesian people is quite high, namely 114.6 kg per person per year. The rice harvest area in 2023 decreased by 2.45%, from 10.45 million hectares to 10.20 million hectares, resulting in rice production which also decreased from 31.54 million tons to 30.90 million tons. The average conversion of paddy fields to non-harvest areas in Indonesia reached 100,000 hectares per year. Meanwhile, the average ability to print rice fields is only 60,000 hectares a year. This means that there is a difference in the conversion of paddy fields of around 40,000 hectares per year. Therefore, the purpose of this study is to elucidate how agricultural technology can enhance rice production across different land types in Indonesia, thus supporting food security efforts. To achieve the objectives of this research, a systematic literature review method was used. The result of this study shows that the amalgamation of diverse technological advancements and innovative practices in rice cultivation holds immense promise in bolstering productivity, bolstering sustainability, and tackling nutritional deficiencies. Prospectively, the use of cutting-edge technology offers some insights that can be input for policy formulation, technological innovation, and community engagement strategies aimed at creating a safer, fairer, and more sustainable food future for Indonesia to achieve food security by 2045.**

Keywords*—rice farming, land conversion, population growth, rice requirement, self-sufficiency

I. Introduction

In an era marked by rapid societal changes and technological progress, ensuring food security remains a critical challenge, particularly for countries like Indonesia with growing populations and diverse agricultural conditions. The current population of Indonesia is 279 million people with the demand for rice as the main food source amounting to 31.2 million tons. It is expected that by 2045, the projected population of Indonesia will reach 318.9 million people, with a population growth rate of 0.41 percent projected during 2040-2045 [1]. Rice is one of the food crops with substantial importance, besides corn and soybeans. The need for rich each year increases in line with population growth and the development of industries that use rice as raw materials [2]. Despite projections indicating that Indonesia will have a surplus of 37.80 million tons of rice by the year 2045, the levels of rice production and domestic consumption suggest the potential necessity for rice imports totaling approximately 15 million tons [3]. This population growth exerts pressure on agricultural systems to enhance productivity and expand production capacities to meet rising food needs.

The emergence of the food security concern has become a widely discussed subject across different regions of the country. Ensuring food security is crucial for meeting the nutritional requirements essential for sustaining a nation's population in the long term [4]. The conversion of agricultural land to non-agriculture in Indonesia in from 1979 to 1999 was around 1,002,005 ha [5]. Indonesia needs to expand its rice area yearly to keep up with the 1.7% annual population growth [6]. Indonesia has around 9.7 million ha of potential land for expanding rice cultivation, consisting of 5.3 million ha of wetlands, 3.0 million ha of swampland, and 1.4 million ha of dry land.

The definition of food security itself is inseparable from the Republic of Indonesia Law Number 18 of 2012 concerning Food, which states "Food Security is the condition of the fulfillment of food for the country up to individuals, reflected in the availability of sufficient, both in quantity and quality, safe, diverse, nutritious, evenly distributed, and affordable food that is not contrary to the religion, beliefs, and culture of society, to be able to live a healthy, active, and sustainably productive life." Additionally, numerous researchers, including [7] exploring its evolution over the past five decades, and discussing its four fundamental pillars: availability, accessibility, utilization, and stability of food. Along with the evolution of food security theory, the utilization of food has emerged as a crucial concern that warrants attention in food security endeavors [8].

As populations expand and demand for food escalates, the challenge of maximizing agricultural productivity within limited land resources becomes more pronounced. Indonesia's reliance on rice as a primary food source underscores the significance of technological advances in maximizing rice yields, optimizing resource utilization, and improving overall agricultural productivity. In parallel, technological innovation emerges as a catalyst for advancing food security objectives in Indonesia. From precision agriculture and biotechnology to digital platforms and supply chain innovations, technology offers transformative solutions to enhance agricultural productivity, resilience, and inclusivity. Additionally, the process of digital transformation holds promise in bolstering food security and alleviating poverty [9]. Digital platforms and data-driven solutions, which are key components of this transformation, empower stakeholders with real-time information, market insights, and decision support tools. This fosters transparency, efficiency, and competitiveness in the food system. Furthermore, cutting-edge technologies have the potential to significantly contribute to sustainability efforts by diminishing environmental footprints, preserving water reservoirs, and alleviating greenhouse gas emissions.

By leveraging technological advancements, Indonesia has the opportunity to overcome existing agricultural constraints and fully utilize its agricultural sector, ensuring food security for Golden Indonesia by 2045.This discourse aims to explain the important factors that shape food security in Indonesia and propose actionable strategies to overcome them using the SLR method. The scientific approach to SLR analysis provides distinct advantages and strengths in comprehensively understanding research problems based on prior studies. Therefore this study aims to examine agricultural technology to achieve food security by 2045 and to provide insights that can be input for policy formulation, technological innovation, and community engagement strategies aimed at creating a safer, fairer, and more sustainable food future for Indonesia.

II. MATERIALS AND METHODS

The research employed a Systematic Literature Review methodology, conducting journal searches in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow guidelines. We constructed our dataset from the Scopus, PubMed and ScienceDirect database, which we accessed via our institution's online library on 2 March 2024. We followed the PRISMA 2020 Guideline (Preferred Reporting Items for Systematic reviews and Meta-Analyses) [10] in our search for technology rice-related studies in Indonesia.

We used the initial search string in Scopus "Technology AND Food AND Security AND Indonesia" and "Technology AND Rice AND Indonesia". In a PubMed search using the keywords "Soil Technology in Indonesia for Rice Yield" and in a ScienceDirect search using the keyword "Technology AND Rice AND Indonesia". Briefly, the flowchart of the algorithm is shown in Figure 1. The selection criteria used are the year of publication from 2014–2024 with the criteria for scientific publications in the form of research articles and selected based on the title and abstract. Contents of all screened journals with appropriate criteria, shows about technology, Rice and food security Indonesia.

The results of the search for journal using Scopus at the beginning of the search with the manual system found 628 documents (results as of 2 March 2024) then screened for the time publication of the journal, type of article (research article and conference paper), by subject areas and the type of access used was open access, resulting in 105 research articles. The search with PubMed resulted in 6, then screened for full text resulting in 3 research articles. The search with ScienceDirect resulted in 12,371, then screened for the time of publication of the journal, the type of document (Research article), the type of access used was open access, and the subject areas were agricultural and biological sciences, resulting in 113 research articles. After being screened for full text, and deducting form article review the journals containing information according to the criteria were obtained fourteen titles.

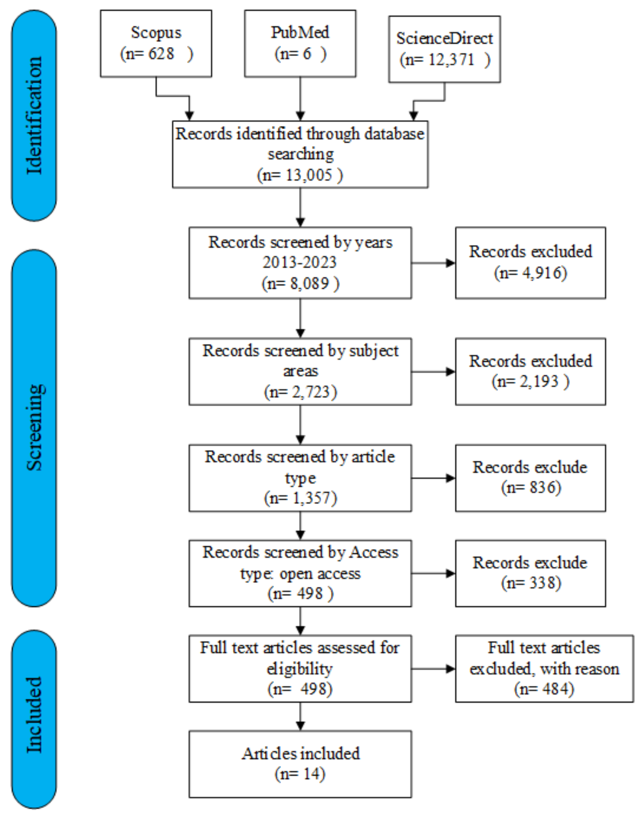

Fig. 1. Flow chart Systematic Literature Review: Revealing Status and Technology to Achieve Food Security in Indonesia.

III. RESULT AND DISCUSSION

The results presented in this article are based on data collected from 2014 to 2024 using PRISMA (Preferred Instrument for Reporting of Studies and Meta-Analysis) on several websites, namely Sciencedirect, Scopus, and PubMed. The results describe various technologies to increase rice yields to achieve food security in Indonesia.

A. Utilization of Technology to Increase Rice Yield in Indonesia

The Indonesian population in the next 40 years will continue to grow with a growth rate of about 1.5% annually, and as a result, the need for food will also continue to increase. It is estimated that by 2025, Indonesia will import about 11.4 million tonnes of rice if wetland conversion still occurs at a rate of 190,000 ha per year and new paddy fields conversions are only 100,000 ha per year [11]. The rate of conversion of paddy fields in Indonesia has reached 100 thousand hectares per year [11], [12]. The highest amount of land conversion occurs in Java, around 75% to 80% [11] The increase in paddy field conversion will have an impact on the decreasing food availability [12].This is a motivation in finding the solution to the problem of rice production. From several research results, it is known that technology applied to rice plants can increase yield to achieve food security in Indonesia, some of the research results are summarized in the table below.

TABLE I. INNOVATIVE TECHNOLOGY FOR ENHANCING RICE PRODUCTIVITY IN INDONESIA

Technology	Variety of Rice	Type of Land	Harvest Yield	References
Cropping System				
Mina Padi Technology	Rice (Oryza sativa L.)	Irrigated rice	The mean rice productivity is 697.93 kg/ha	Dewi, 2023
Development of rice varieties	Pigmented rice	Irrigated Lowland, Upland, and Swampy areas	The yield average is 4,83-6.21 t ha− 1	Trias, 2023
Rice varieties, fertilizer application, and planting system	Inpari 30, Inpari 32, and Mekongga	Irrigated rice	The highest grain yield was 9.19 t/ha	Musfal, 2023
Jajar Legowo Super (Jarwo Super) Technology	Inpari 39 and Inpari 43 varieties	Irrigated rice	Rice productivity is 34.7% and 35.5% in 2019 and 2020	Kusumawati, 2022
SALIBU technology	Rice varieties Madang Pulau, Anak Daro, Batang Piaman, Lumuik, Cisokan, Hibrida Hipa-3, Inpari-12, Inpari-21, Logawa	Highland and lowland areas	Rice grain is 10.3% higher than conventional technology. Crop intensities of more than 250% annually and produced 22.1 ton/ha/year of rice grain	Fitri, 2019
Floating Rice Cultivation	Ciherang	Lowland rice	The average rice productivity was 11.58 tons ha-1	Mujiyo, 2022
Inorganic based Fertilizer Technology				
Soil tillage and nitrogen fertilizer management	Rice (Oryza sativa L.)	Irrigated rice	Grain yield with maximum tillage was 119 kg methane ha−1 per season	Wihardjaka, 2022
Organic-based Integrated Fertilizer Technology				
Bioameliorant and Biofertilizers	Rice Ciherang	Irrigated rice	The rice grain yield was increased from 7.1 tons per ha to 8.41 tons ha−1 (11.3-42.3% higher)	Simarmata, 2016
Stem Cutting Sizes and Seprint Liquid Organic Fertilizer	Rice variety Inpari 30	Lowland rice	Harvest yield per hectare of ratoon rice is 3.12 tons ha−1	Alridiwirsah, 2021
Halotolerant Plant Growth-Promoting Rhizobacteria	Rice (Oryza sativa L.)	Saline Soil	The highest grain yield was 7.0 t/ha	Hanum, 2022
Multi-Omics Technologies (proteomics, transcriptomics, metagenomics, and metabolomics)	Rice (Oryza sativa L.)	Irrigated rice	Enhance N uptake and increase yield up to 67%-93%.	Doni, 2022
Water Saving Technology				
Managing of Organic - Biofertilizers Nutrient Based and	Rice (Oryza sativa L.)	Irrigated rice	Rice grain yield ranged from 6-11 t ha-1 was increased by	Simarmata, 2018

Water Saving Technology, known as "IPATBO"			50-200 %. IPATBO has a great prospect to increase the productivity from 5-6 to 6-8 tons ha−1 of rice grain yield	

1. Mina Padi Cultivation Technology

Mina Padi techniques in Indonesia have been introduced since the mid-19th century. Adopting this technology benefits farmers and can ensure that its agricultural sector remains resilient, sustainable, and capable of handling future food security challenges. The implementation of Mina Padi has resulted in a significant production rate increase of 10-20 percent, reaching 6-7.5 tonnes of rice per hectare per harvest, accompanied by an additional 1-2 tonnes of fish per hectare. Semampir farmers implement the Mina Padi design by creating a 10-meter paddy field with a canal running through the middle, measuring approximately 40 cm in length and 59cm in width. These canals are waterways for regulating water flow and irrigation within the fields. Bunds are constructed along the field edges as barriers to retain water and prevent overflow. Near the access point, a pool is built, sized according to the plot width and approximately 10% of the plot area, to collect and store water for irrigation. Additionally, a ditch measuring 60 cm in depth and 80 cm in width is connected to the pond, running parallel to the plot, serving as a drainage channel to facilitate the removal of excess water and prevent waterlogging.

2. Digital Model Technology

- Soil Fertilizer Technology

There are several factors that influence farmers' choices in soil fertilizer technology, including the use of new superior varieties, location-specific fertilization, balanced use of inorganic and organic fertilizers, soil fertility testing, conservation technology for land, and autonomous technologies such as tractors, fertilizer scattering drones, seed scattering drones, and robots.

- Water-saving Irrigation Technology

Water-efficient irrigation can increase irrigation sailing, the planting index, and the planted area to increase agricultural production. However, the development of water-efficient irrigation is hindered by various management issues, including the maintenance of water infrastructure buildings and water resources, and the problem of water utilization and distribution. Water-efficient irrigation technology is based on the principle of providing irrigation based on the minimum water requirement of the soil. As a result, plants are irrigated with only the minimum amount of water they need, which is lower than their usual requirements.

- Green Technology

Digitization through fertilizer aims to control soil fertility levels with the help of organic and inorganic fertilisers.In the era of green technology, fertilization is based on increasing the energy mix of new and renewable energy by 10 GW, consisting of 6 GW of gas-based energy, 3 GW of renewable energy, and 1 GW of new energy, in which includes hydrogen. The success of increasing the productivity of food crops followed by environmental sustainability is the principle of applying a sustainable, environmentally friendly agricultural system.

- Digital Marketing Technology

Digital marketing can be used as an alternative to convey information on developments in agriculture. It can create a more effective and efficient sales system, but only 15% of farmers use digital marketing technology, while 66.45% do not. The majority of farmers still sell agricultural products to middlemen (67%), and 85 respondents still do not use agricultural platforms for sales. Given these findings, researchers must provide socialisation and assistance in handling and packaging agricultural products to increase their added value and selling prices. Farmers should also be equipped with online agricultural product marketing activities, such as selling online on social media, to increase efficiency and effectiveness

3. Row Planting Systems and Seed Varieties

The plant population in PT. I (May 2021) seem to be affected by the cropping system for rice plants. The row legowo planting system (2:1) gave the highest plant population, followed by the row legowo planting system (4:1) and the lowest plant population was according to the Tegel planting system.

The rice planting system as a component of cultivation will affect the yield, according to Makarim et al., several processes influence it, including the capture of solar radiation by plants for photosynthesis, absorption of nutrients by plants, plant water requirements, circulation of CO2 and O2, the results of photosynthesis, the availability of space that determines the weed population, and the microclimate under the canopy that affects the development of plant-disturbing organisms.

The results of the PT. I activities (May 2021) showed that the jajar legowo planting system (2:1) on average gave the highest grain yield for the three varieties tested, then it was not significantly different from the row legowo planting system (4:1). The Tegel method gave significantly lower yields than the jajar legowo planting system. The highest average yield was given by the Inpari 32 variety, followed by the Mekongga variety, and the lowest by the Inpari 30 variety. Of the three varieties tested, the Inpari 32 variety on average gave higher yields than the Mekongga and Inpari 30 varieties, both planted according to the row of legowo (2:1) or the Tegel method. While the method of planting system jajar legowo (4:1) the Mekongga variety gave the highest yield compared to the Inpari 32 and Inpari 30 varieties. The highest grain yield was 9.19 t ha-1 provided by the Inpari 32 variety, followed by the Mekongga variety at 8.30 t ha-1. where these two varieties were grown according to the row legowo (2:1) cropping system, while the lowest yield of 6.55 t ha-1 was given by the Inpari 30 variety which was grown according to the Tegel method.

4. Crop Model Simulations

The crop model ORYZA v3 [13] was used to simulate the three variants of Yp considered in this study (Fig. 1). These Yp variants were simulated for each surveyed field in each site where the farm surveys were conducted. The ORYZA v3 model, and its earlier versions, has been extensively calibrated and evaluated to simulate Yp for rice in the main irrigated rice areas of Southeast Asia [14], [15], [16], [17], [18]. The model represents rice crop development and growth in response to genotypic, environmental and management factors, and their interactions, considering mechanistic and empirical relationships that are described in [19] and [13]. The factors considered in the simulation of Yp included daily weather data for each site where the farm surveys were conducted (Table 1) as well as field-specific farmers' reported rice varieties, crop establishment method and sowing dates (Table 2).The main differences between these calibrated varieties in ORYZA v3 are the thermal times controlling crop development and some of the parameters controlling leaf growth and biomass production. Further details about the calibration of the different varieties in ORYZA v3 are reported elsewhere and the calibrated crop files for each variety can be found in Online.

IV. Current and Future Challenges

The results of the assessment of the sustainability analysis of the five dimensions, namely the ecological dimension, the economic, socio-cultural, technological and institutional dimensions show that the aspects of socio-cultural and technological dimensions are less sustainable in supporting the sustainability of food self-sufficiency. The factors of using certified seeds, the use of rice production tools and machinery, the size of paddy fields, the size of irrigated paddy fields and the cropping index are key factors in the technological aspect that can support the sustainability of food self-sufficiency. These factors can have a positive influence on the production of rice staple food in order to support sustainability of food self-sufficiency if the condition of these factors increases, but on the contrary can decrease food production if their existence decreases

Looking ahead, much still needs to be done to foster agricultural development. Many adoption studies are still largely a snapshot of a situation that reports adoption as a binary outcome and seldom addresses whether adoption continues over several years and/or the intensity of the adoption i.e., the percentage of land area that a farmer uses for agricultural innovation. Furthermore, a key challenge is the scaling out of these technologies to greater numbers of farmers and scaling up in terms of fostering the organizational, governance and policy environments that encourage scaling. Furthermore, this scaling has to enhance social equity and foster improved livelihood trajectories, including off-farm ones.

V. Conclusion

In conclusion, if it is projected, the population of Indonesia in 2045 will reach 318.9 million people, with a population growth rate of 0.41 percent. The amalgamation of diverse technological advancements and innovative practices in rice cultivation holds immense promise in bolstering productivity, bolstering sustainability, and tackling nutritional deficiencies. These approaches, ranging from varietal selection and cropping systems to soil management techniques and the utilization of microorganisms, have demonstrated notable success in elevating rice yields, mitigating environmental impacts, and enhancing nutritional value.

So, the solution that can be implemented is by increasing productivity using technology (from 5 tons to 6 tons), increasing the area area by approximately 250 thousand/ha per year to 12.5 million ha multiplied by 2 harvests to become 25 million ha of harvest area. Nevertheless, to fully harness the potential benefits of these advancements, concerted efforts in further research and widespread adoption are imperative. Comprehensive studies across various rice-growing regions are necessary to fine-tune these practices according to local conditions and requirements. Additionally, dissemination of knowledge and resources to farmers, along with supportive policies and investment, will play pivotal roles in facilitating the widespread adoption of these technologies. By embracing such endeavors, the rice cultivation sector can realize substantial improvements in productivity, sustainability, and nutritional outcomes on a global scale.

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