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CASE STUDY

Cocoa farmers' characteristics on climate variability and its effects on climate change adaptation strategy

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ABSTRACT

BACKGROUND AND OBJECTIVES: Climate change has a greater influence on agriculture through local climate variability than global climate patterns. The impact of climate change on agricultural productivity and shifts in crop patterns varies significantly across regions. Its impact is closely tied to the technical abilities of farmers in managing their cocoa farming businesses. Technical skills encompass the proficiency of farmers in adopting adaptive cocoa cultivation techniques for planting, maintaining cocoa plants, as well as handling harvest and postharvest processes. The technical capability is interconnected with factors such as crop dependency on rainfall patterns, availability of infrastructure for quality inputs, soil degradation and fertility, nutrient levels, limited farmers' resources, and technology penetration. Given the significant impact of climate change on cocoa farmers, it becomes crucial to enhance their adaptive capacity to address these challenges. Therefore, this study aimed to analyze the relationship between the characteristics of farmers and their adaptive capacity in responding to the impact of climate change.
METHODS: Data were collected from 960 populations from two regencies, 4 districts, and 8 villages using the stratified sampling technique through interviews with 282 respondents. The sample size was determined using the Slovin formula through in-depth interviews with five key informants. The data collected were descriptively and statistically analyzed using the Excel program, which involved generating frequency distribution tables. Furthermore, the Mann-Whitney test, utilizing Statistical Product and Service Solution version 24, was employed to conduct a comparative analysis.
FINDINGS: This result showed that the characteristics of farmers in the two areas were relatively the same in terms of age, non-formal education, number of family dependents, and perceptions of the climate. In terms of age, most farmers fell within the mature group of 36-48 years, with an average age of 44.63, considering in low category. The low productive age of farmers (44.63), along with their non-formal education, including training in climate field schools and integrated pest management field schools, as well as the number of dependents and their perceptions of climate change, emerged as significant parameters impacting farmers' decision-making processes. These factors also influenced their ability to cope, adapt, and seek new approaches to manage and mitigate the effects of climate change on their farming operations.
CONCLUSION: The relationship between farmers' characteristics and adaptive capacity showed that the larger the land owned by farmers, the higher the managerial adaptability of farmers with lower technical ability.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
43	3	4

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INTRODUCTION

Indonesia has consistently ranked as one of the world's top three cocoa producers for the past twenty years, producing 656,817 tons in 2016 (FAO, 2017). More than half of cocoa are smallholders in Sulawesi, who account for about 60 to 71% of the national production. However, climate change poses significant challenges for cocoa cultivation, impacting the biophysical environment of the plant as well as the socioeconomic conditions of farmers (Feola *et al.,* 2015; Schroth *et al.,* 2016; Frimawaty *et al.,* 2023). Luwu and North Luwu Regencies, which serve as major cocoa production centres and cover 61.4% of the national cocoa area, are particularly affected by climate change. It is characterized by changes in rainfall patterns leading to high humidity and increased attacks by pests and diseases during the rainy season. Conversely, prolonged dry seasons result in flower loss, wilting, plant mortality, and reduced cocoa production. On average, climate change has caused a decline in cocoa production from 800-1000 kilograms per hectare per year (kg/ha/y) to 600 kg/ha/y. For instance, cocoa production in North Luwu Regency was 30,854.56 tons in 2020, from a land area of 40,814.56 ha, but decreased to 28,573.37 tons in 2021 (Oyekale, 2018; Idawati *et al*., 2019). This means that water availability plays a critical role in the physiological processes of cocoa plants, either directly or indirectly. Therefore, adaptation efforts in minimizing vulnerability to exposure, sensitivity, and adaptive capacity are needed to overcome these impacts. Farmers' ability to adopt information and technology is a key factor in determining their adaptive capacity. It is closely linked to individual farmers' characteristics, such as their education, age, farming experience, number of dependents, income level, land area, perception of climate, risk assessment, and evaluation of information. The adaptive capacity of cocoa farmers is influenced by a) their characteristics in non-formal education which consists of training, Climate Field Schools, Integrated Pest Management Field Schools, and length of farming that influences decision making, b) Counseling support from the government, private and self-help groups in increasing the ability and mastery of climate-adaptive material for extension workers, and c) government support in climate information services and availability of farming capital for cocoa farmers to realize sustainable cocoa farming. The challenge of sustainable livelihoods of rural farmers in the context of climate change is in accordance with the response to government policy on mitigation strategies (Asante *et al.,* 2017). Non-formal education plays a significant role in fostering farmers' acceptance of extension activities in the two regencies. According to Suh and Molua (2022), non-formal education provides practical learning opportunities outside traditional classrooms or field schools. It employs adult learning methods that effectively address specific problems and align with the goals and targets of the learners. In addition, non-formal education also influences farmers' attitudes, actions, and mindsets, enabling them to make innovative decisions, increase productivity, improve the quality of their work, and expedite task completion. Private extension workers, who have firsthand experience and success in cocoa farming, play a crucial role in delivering non-formal education to doctors who are skilled farmers. They serve as direct examples and provide practical guidance to the surrounding farmers. These extension workers undergo training programs conducted by cocoa plantation agribusiness management partners, including governmental and corporate entities. These partners are assigned to assist and support farmers in their respective target areas. The presence of government, private, and non-governmental extension agents varies in terms of their duties and functions in the field. They collaborate to address implementation challenges related to climate change mitigation strategies (Ameyaw *et al.,* 2018), comprehensive evaluation of integrated energy plantation models for cocoa production (Wessel and Quist-Wessel, 2015), and climate change adaptation and mitigation strategies for cocoa farmers. These strategies include ensuring sufficient water availability, managing pest attacks and diseases, and addressing the threats of floods and droughts. It is also essential to understand cocoa farmers' perceptions of climate change, the availability of capital, extension support, and the involvement of the private sector in enhancing adaptability to the impacts of climate change (Kosoe and Ahmed, 2022). These factors contribute to the sustainability of cocoa farmers' lives and their families (Peprah, 2015). Moreover, it is important to recognize non-climate stressors in semi-arid areas (Ahmed *et al*., 2016) and consider cocoa farmers' perceptions of climate variability (Ehiakpor *et al.*, 2016). Given the background mentioned above, this study aims to analyze the relationship between cocoa farmers' characteristics and adaptive capacity in managing farming business in the face of climate change in 2022.

MATERIALS AND METHODS

Study area

This study was conducted from October to December 2022 in Luwu and North Luwu Regencies, South Sulawesi Province, Indonesia. The map of the study site locations is shown in Fig. 1.

Data collection

The target population for this study consisted of cocoa farmers who met specific criteria, including being actively involved in managing cocoa plantations and authorized to make decisions. The sample size of 282 farmers was determined from a total of 960 eligible agribusiness actors using the Slovin equation. The distribution of the sample was conducted across several villages in different districts, including Batu Lappa and La'loa Villages in South Larompong District, Lamasi Pantai and Pompengan Villages in East Walenrang District, Marobo and Bakka Villages in Sabbang District, as well as Teteuri and Terpedo Jaya

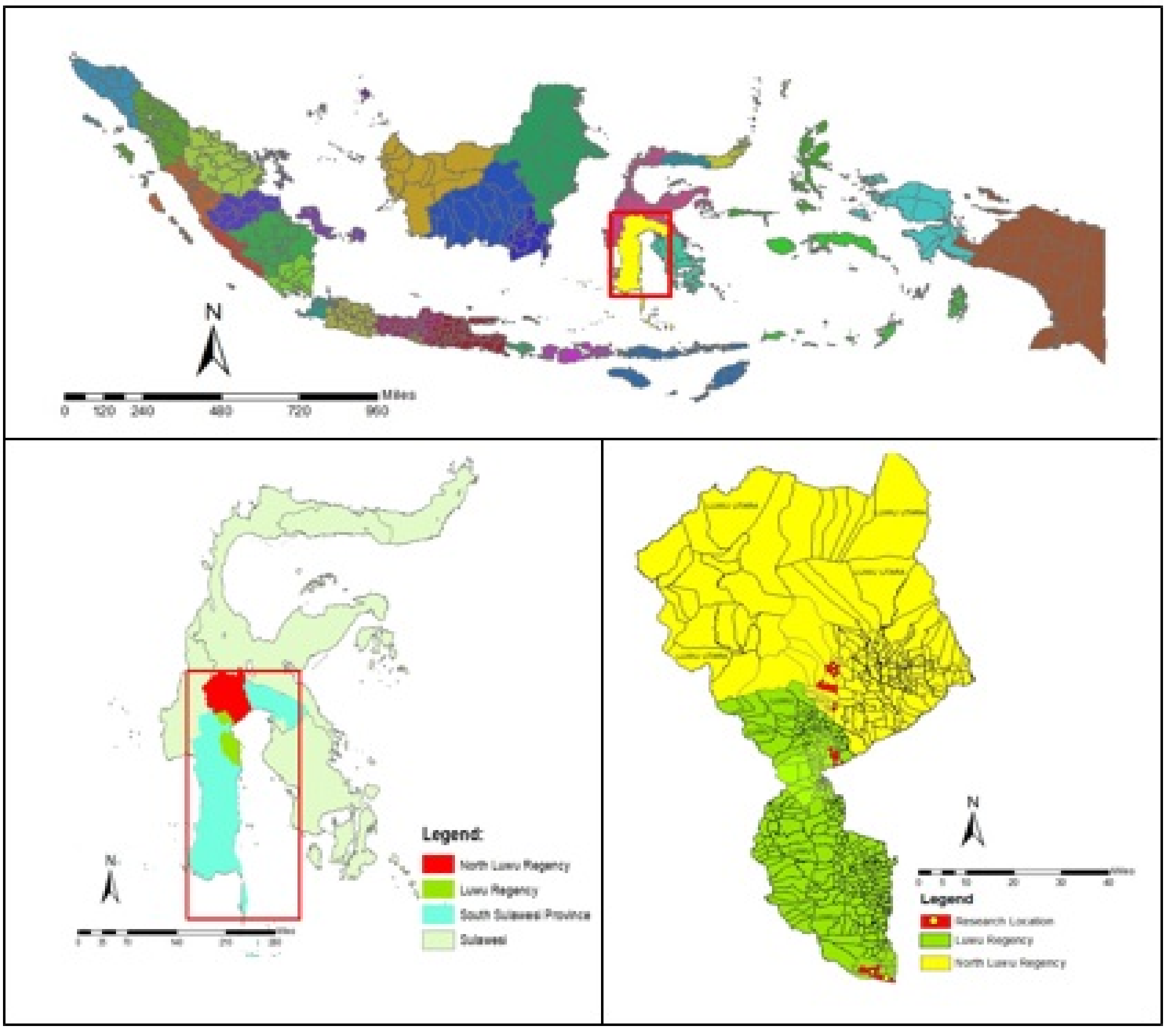

Fig. 1: Geographic location of the study area in Luwu and North Luwu Regencies, Indonesia

Table 1: The distribution of locations, population, and study samples

Regency	District	Village	Total population (person)	Farmers' group/sample (person)
Luwu	South Larompong	Batu Lappa	150	44
		La'loa	100	29
	East Walenrang	Lamasi Pantai	125	37
		Pompengan	60	18
North Luwu	Sabbang	Marobo	110	32
		Bakka	125	37
	South Sabbang	Teteuri	170	50
		Terpedo Jaya	120	35
Total			960	282

Villages in South Sabbang District. Data collection from respondents in each village was carried out using stratified sampling, targeting specific farmers' groups within each village. From the eight selected villages, one farmers' group was randomly selected, ensuring the inclusion of both members and administrators, using a simple random sampling method in accordance with the group's specific provisions, as shown in Table 1.

The questionnaire used was tested for validity using the Pearson Product Moment correlation with a calculated value of 0.603-0.966 (r is greater (>) than the table r value). Reliability testing was performed using the Cronbach Alpha method, which measured the correlation coefficient between 0 and 1. The questionnaire exhibited a reliability range of 0.743 across its items. These validation and reliability tests were conducted outside the study population using similar characteristics and conditions to the respondents. Specifically, the tests were performed among 30 farmers in the Siwata Farmer Group in Noling Village, Luwu Regency.

Statistical analysis

Structured interviews were conducted with 282 respondents using questionnaires. Additionally, in-depth interviews were carried out with five key informants, consisting of extension workers, coordinators of private partners (PT Mars Sustainability Indonesia), community leaders, and officials from the Department of Agriculture and other relevant institutions. The questionnaires used a Likert scale to measure respondents' opinions or feelings, with categories ranging from strongly disagree (1.00-1.99), undecided (2.00-2.99), agree (3.00-3.99), to strongly agree (4). The collected interview data and results were tabulated and analyzed descriptively and qualitatively using frequency tables in the Excel program. This analysis aimed to provide an overview of the characteristics and adaptability of farmers. The Mann-Whitney test was employed for statistical analysis using the social science software (SPSS) version 24. This study also sought to explore the relationship between the characteristics of cocoa farmers and their adaptive capacity through inferential statistical analysis using Spearman's Rank correlation. Qualitative data were used to complement and describe the quantitative data findings.

RESULTS AND DISCUSSION

Rainfall conditions in Luwu and North Luwu Regencies

The rainfall patterns and the number of rainy days in Luwu Regency from 2020 to 2022 are illustrated in Fig. 2. The data showed that rainfall was significantly low or even absent from July to November. This indicates that the climatic conditions over the past four years have impacted the physiological processes of cocoa plants during those years and may continue to affect them in the future. Cocoa plants generally thrive when rainfall is evenly distributed in the year. Fluctuations in rainfall can have adverse effects on cocoa plants' physiological processes. During the dry season, cocoa plant growth is inhibited, and the fruit may fall prematurely at approximately two months of age. Conversely, excessive humidity during the rainy season can lead to fruit rot and increased susceptibility to pests, necessitating regular pruning. The distribution of cocoa cultivation

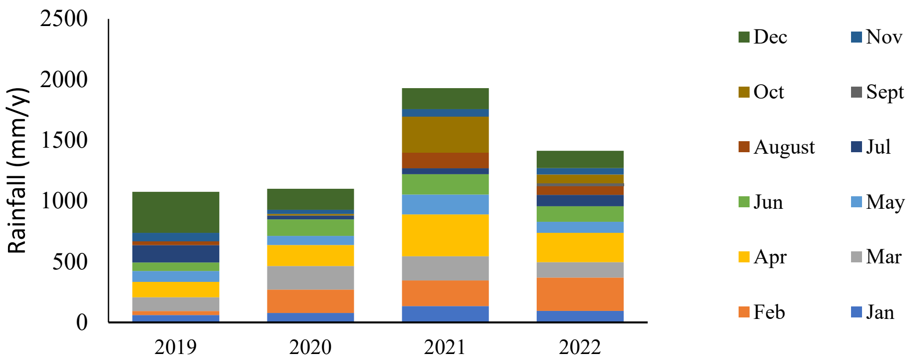

Fig. 2: Annual rainfall in the study sites Luwu and North Luwu Regencies

is typically observed between 7 degrees North Latitude (NL) and 18 degrees South Latitude (SL), corresponding to the rainfall and sunshine patterns throughout the year. However, cocoa can still be grown in regions of 20 NL to 20 SL, making Indonesia, located between 5 NL and 10 SL, suitable for cocoa cultivation. The ideal altitude for cocoa cultivation in Indonesia is below 800 meters above sea level (asl).

According to Riyanto *et al*. (2022), the upper slopes at an elevation of 900 meters above sea level (asl) have a significantly higher potential phosphate (P) content compared to the lower slopes. This indicates variations in nutrient availability in the soil, highlighting the importance of using fertilizers containing P elements, specifically on lower slopes. For optimal cocoa growth, the ideal rainfall distribution is consistent in the year, with an average annual rainfall ranging from 1,100 to 3,000 mm. Rainfall exceeding 4,500 mm/year is unfavorable as it is closely associated with the occurrence of fruit rot disease. In areas with rainfall below 1,200 mm/year, cocoa cultivation is still feasible but will require irrigation. This is because the amount of water lost through transpiration by the plants would exceed the water received from rainfall alone.

Characteristics of farmers

The analysis of farmers' characteristics in the two regencies revealed several similarities and differences. The characteristics that showed relatively similar values between the regencies were age, non-formal education, number of dependents, and farmers' perceptions of the climate. On the other hand, the characteristics that differed between the regencies were formal education, agribusiness experience, land area, cosmopolitanism, and information exposure, as shown in Table 2. In terms of age, the majority of farmers in both regencies fell within the mature category, ranging from 36 to 48 years old, with an average age of 44.63. This age group is considered productive and allows farmers to focus on the development of their cocoa farming business. This finding is consistent with the study by (Anning *et al*., 2022) that those between 44-64 years are of productive age because the farmers are still young, with the potential and physical ability to ensure adequate management. Farmers still showed enthusiasm and motivation to care for their farming business, accept innovation, and change lives by earning a better income. Arifah *et al.* (2022) stated that the productive age of cocoa farmers significantly influenced their farming abilities. Those in this age group can implement good cultivation practices and make decisions, including adopting new knowledge and technologies for cocoa cultivation. Farmers at this age can quickly make decisions through the support of ideas and information while still actively participating in agricultural extension activities. The number of family dependents also plays a crucial role in determining the effectiveness of extension agents in influencing farmers' behavior. The number of family dependents can have positive and negative implications for farmers. A small number of dependents or having non-productive family

Table 2: Frequency distribution of cocoa farmers according to individual characteristics in Luwu and North Luwu Regencies

Individual characteristic	Category	Regency		Mann Whitney difference test
		Luwu (%)	North Luwu (%)	
Average age = 44.63	Young (24-26.25 years)	18.75	21.43	0.242
	Adults (36.26-48.50 years)	50.78	55.84	
	Old (48.51-60.75 years)	26.56	20.13	
	Very Old (60.76-73 years)	3.91	2.60	
Average formal education = 8.77	Very Low (Elementary School)	34.38	29.87	0.011**
	Junior High School	41.41	27.92	
	Senior High School	24.22	42.21	
	Higher Education (University)	0.00	0.00	
Average non-formal education = 3.72	Very Low (1-2.5)	10.94	27.92	0.208
	Low (2.51-4)	61.72	16.23	
	High (4.1-5.5)	27.34	44.16	
	Very High (5.51-7)	0.00	11.69	
Average agribusiness experience = 17.87	Very Low (3-9.75 Tahun)	5.47	9.74	0.038*
	Low (9.76-16.50 Tahun)	33.59	39.61	
	High (16.51-23.25 Tahun)	35.94	29.87	
	Very High (23.26-30 Tahun)	25.00	20.78	
Average land area = 1.25	Narrow (0.5-1 ha)	73.44	28.57	0.000**
	Medium (1.1-2 ha)	25.00	70.78	
	Large (3.1-4 ha)	0,78	0.00	
	Vast (4.1-5 ha)	0,78	0,65	
The average number of dependents = 4.96	Very Low (3-4 people)	58.00	46.10	0.742
	Low (4.1-5 people)	17.00	17.53	
	High (5.1-6 people)	44.00	28.57	
	Very High (6.1-7 people)	9.00	7.79	
Average cosmopolitanism = 3.84	Very Low (2-3)	23.44	22.73	0.001**
	Low (3.1-4)	46.88	20.13	
	High (4.1-5)	27.34	54.55	
	Very High (5.1-6)	2.34	2.60	
Average information exposure = 5.71	Very Low (3-4.75)	21.09	29.22	0.000**
	Low (4.76-6.50)	56.25	31.82	
	High (6.51-8.25)	15.63	35.06	
	Very High (8.26-10)	7.03	3.90	
Average Farmer's Perception of Climate = 20.83	Very Low (10-14.25)	17.97	7.79	0.495
	Low (14.26-18.52)	0.00	0.00	
	High (18.52-22.76)	54.69	64.29	
	Very High (22.77-27)	27.34	27.92	

*significantly different at the level of 0.05 ** significantly different at the level of 0.01

members can contribute to household poverty. However, the presence of family dependents, particularly those in the productive age range, can motivate farmers to expand their businesses and increase their income. In cocoa farming, having family members who can contribute to labour can be beneficial. Coopmans *et al*., (2021) stated that family dependents in the productive age range could provide additional labour for cocoa farming activities. This can help farmers manage their farms more effectively and increase productivity. The number of dependents can also serve as a source of motivation for them to work harder and achieve greater success. Farmers may be driven to increase their efforts and income generation to support the needs and welfare of their family members. Additionally, their perceptions in the two regencies regarding climate change were relatively similar, indicating a shared understanding of the challenges they face and the need for adaptation, as shown in Table 1. According to (May *et al.,* 2019), some of the internal characteristics, such as education, age, and area of arable land, influence farmers' decision-making process to implement adaptive choices related to climate change. They acknowledged the impact of climate change on cocoa plants and

Table 3: Distribution of cocoa farmers based on their adaptive capacity in the two study locations in Luwu and North Luwu Regencies

Farmers' adaptive capacity	Category	Regency		Mann Whitney difference test
		Luwu (%)	North Luwu (%)	
Average technical ability = 17.20	Very Low (8-13)	14.84	30.52	0.002**
	Low (13.1-18)	43.75	23.38	
	High (18.1-23)	25.78	46.10	
	Very High (23.1-28)	15.63	0.00	
Average managerial Ability = 12.40	Very Low (5-8.25)	7.81	5.19	0.000**
	Low (8.26-11.50)	55.47	21.43	
	High (11.51-14.75)	21.88	55.84	
	Very High (14.76-18)	14.84	17.53	
Average socio-cultural ability = 18.73	Very Low (10-13.5)	12.50	2.60	0.000**
	Low (13.51-17)	21.09	8.44	
	High (17.1-20.5)	49.22	54.55	
	Very High (20.51-24)	17.19	34.42	

*significantly different at the level of 0.05 ** significantly different at the level of 0.01

recognized the importance of implementing Good Agriculture Practices (GAP) and other techniques such as pruning, pest control, fertilizing, and sanitation (P3SP) to ensure optimal farming care. This is in accordance with the findings of (Asante *et al.,* 2022) regarding the influence of rainfall and temperature changes on cocoa cultivation. The analysis in Table 2 showed significant differences between the two regencies regarding formal education, agribusiness experience, land area, cosmopolitanism, and exposure to information, with higher values observed in North Luwu Regency. This showed that cocoa farmers in North Luwu Regency had better access to information and were more engaged in managing their businesses, potentially due to policy support and attention from the local government. The involvement of the private sector, as exemplified by the Sustainable Farming in Tropical Asian Landscape (SFITAL) Program and collaborations between various stakeholders, including the private sector, government, universities, and farmers, contributed to the optimization of cocoa farming practices in North Luwu Regency. These collaborative efforts aimed to establish a sustainable cocoa roadmap and achieve common goals in cocoa production (Tothmihaly *et al.*, 2019). The presence of the private sector served as a motivating factor and played a role in influencing farmers' behavior and success in managing their agribusinesses, particularly in North Luwu Regency.

Farmers' Adaptive Capacity in Overcoming the Climate Change Impacts

The analysis results of cocoa farmers' adaptive capacity in the two regencies in Table 3 showed that their technical, managerial, and socio-cultural adaptive capacities differed. The percentage of farmers with technical and managerial skills was low in Luwu but high in North Luwu. On the other hand, both regencies showed high levels of socio-cultural adaptive capacity.

Technical ability

The statistical test results indicate significant differences in the technical adaptation abilities between the two regencies, as well as variations in farmers' distribution. The technical ability scores for both Luwu and North Luwu Regencies were 17.20 (Table 3) and in the low category. In general, the unique tropical climate of both regencies, characterized by distinct rainy and dry seasons, directly influences cocoa farming practices from a technical standpoint. When the technical abilities of farmers in the two regencies were compared, Luwu exhibited lower scores than North Luwu. The key technical skills assessed were regular monitoring of soil pH, utilization of organic fertilizers, biannual soil liming, manual weed removal (without herbicides), appropriate disposal of cocoa shells, and sanitation practices. Others include a) cocoa GAP techniques, b) water-saving technology, management and use,

c) implementation of Climate Field Schools and Integrated Pest Management Field Schools, d) demonstration plots/gardens, e) plant rejuvenation by carrying out crop diversification (agroforestry concept), and f) application of a climate adaptation cacao cultivation calendar. The findings of this research are in accordance with the study conducted by (Daniele *et al.,* 2022), which stated the varying degrees of adaptation abilities among Danish farmers. Some of them expressed indifference toward the impact of climate change and encountered obstacles to adaptation, while others recognized ongoing efforts as proactive actions to capitalize on potential opportunities arising from climate change impacts. The technical ability assessed in this study focused on implementing GAP for cultivating cocoa plants, with specific emphasis on adaptive strategies to address climate change, including the P3SP approach. However, the findings revealed that the technical capacity of farmers was still very low due to their failure to apply the climate-adaptive GAP technique during the initial stages of cocoa tree planting. The adaptive technical ability of farmers is demonstrated when they effectively carry out maintenance activities in accordance with GAP techniques, particularly those that are climate-adaptive. These climate-adaptive practices are in accordance with the cocoa cultivation calendar, which serves as a guideline for growing cocoa plants and allows farmers to adapt their practices to local weather conditions. The technical ability of farmers in North Luwu Regency excelled in areas such as plant pest organism (PPO) control and weed management, according to the specific timing outlined in the cocoa cultivation calendar. They also showed adaptive behavior by following the cocoa cultivation calendar, which aimed at increasing cocoa productivity and supported by external assistance provided by partners. This is in accordance with the findings of Dessart *et al.* (2019), stating that the adaptive capacity of farmers was influenced by internal factors such as land area, family size, and understanding of climate change. These factors enable farmers to manage their cultivation activities following prevailing weather conditions effectively. Additionally, external support from decision-making bodies and relevant stakeholders plays a crucial role in enhancing farmers' access to market information, loans, services, counselling, and involvement in study, thereby offering solutions to agricultural challenges associated with climate change adaptation. Buitenhuis *et al.* (2020) recommended increasing the involvement of group leaders, providing training opportunities, and strengthening cooperation among stakeholders to overcome disharmonious relations between relevant stakeholders, government and private institutions. Furthermore, the presence of assistants or facilitators who can foster better relationships between cocoa farmers and stakeholders is essential. Taking these measures makes it possible to overcome deadlocks and minimize communication barriers, ultimately achieving better communication convergence among all stakeholders involved in the cocoa farming sector.

Managerial ability

The average managerial ability in the two regencies was significantly different, with an average score of 12.40 in the high category. Managerial ability encompasses various indicators, including financial record-keeping, allocation of capital for the next season, fertilizer usage calculation, cocoa seedling requirements during rejuvenation, and efficient use of labour. In Luwu Regency, these indicators were found to be in a low category, indicating a lower level of managerial ability than in North Luwu Regency, as shown in Table 3. Farmers in Luwu Regency focused on setting aside farming capital for the following season and maintaining financial records. However, they faced challenges in allocating sufficient funds for their farming business due to the difficulties in generating income, which led to a decline in production. The income earned primarily met basic family needs, leaving little capital available for farming. Consequently, farmers estimated their capital requirements based on financial resources without a comprehensive and detailed farming business plan. To address these challenges, it is crucial to enhance farmers' understanding of the circular economy concept, which emphasizes optimizing the utilization of resources and promoting sustainable farming practices. This includes improving the farmers' managerial cycle processes, such as effectively managing inputs and reusing resources as farming capital, updating farming business plans, and understanding the production process and the recycling of raw materials needed for cocoa products. The circular economy is a closed economic, managerial cycle system that aims to maintain the value of products, by-products, and materials within the supply chain process (Sasongko & Pertiwi, 2021). This system can be integrated as a component within different areas, with varying impacts at the local and wider levels. The value chain of circular economic products and services presents opportunities for various areas with unique characteristics and effects. Coopmans *et al.* (2021) identified four internal factors that influenced the adaptability of farmers. The first factor is the personal characteristics of the farmers, including their ability to recognize talents and skills, self-motivation, problem-solving capabilities, adherence to norms, values, customs, culture, ideas, and emotional control. These factors play a significant role in agricultural management decision-making and are closely related to farmers' motivation, such as their desire for self-actualization versus economic considerations, as well as the survival of farmers and their families. The second factor is the initial involvement in farming and family habits that affect complex social life, including gender. The third factor is career paths, where higher formal education and work experience in non-agricultural sectors may deter the younger generation from pursuing careers in agriculture, resulting in a lack of interest and ability among the youth in the agricultural sector. The fourth factor is the individual's perception of agriculture. Farmers' perceptions influence their ability to manage time between work and family life, which in turn affects socio-cultural aspects (e.g., primogeniture, gender roles) and sociological factors (e.g., modernization, individualization) in their managerial adaptation within cocoa farming (Sianipar, 2022).

Socio-cultural ability

Socio-cultural ability exhibited significant differences between the two regencies, with an average score of 18.73, indicating a high ability level. This disparity was evident in farmers' participation in activities organized by partner companies, who not only provided counselling on cocoa farming but also purchased the products, as shown in Table 3. The local culture of farmers further contributed to this discrepancy, as indigenous people tended to settle down, retire early, and transfer their land to migrants from Bugis, Makassar, Enrekang, Java, and Toraja. The advanced age of the farmers also influenced their physical fitness and work ethic, exacerbating the lack of regeneration in the agricultural business. According to Meuwissen *et al.* (2019), supporting factors of agricultural production are closely related to the family in the context of social dynamics. The first factor is human capital, one of the agricultural succession supports. Successful farmers possess the necessary skills to navigate personal, household, and entrepreneurial challenges. Therefore, learning capacity is needed to face various dangerous challenges in the development and sustainability of agriculture. The second is interpersonal dynamics which are defined as participation and reciprocal interaction between fellow farmers and the involvement of supporting factors as socio-economic networks in the agricultural sector. Prain *et al.* (2020) further investigated the influence of roles and interpersonal dynamics on technology transfer in the livestock sector, and examined how these factors impacted farmers and the local community. The ability to communicate and collaborate effectively relies heavily on the local cultural context of the two regencies, as well as the government's involvement in decision-making processes that engage all relevant stakeholders. The third factor is the characteristics of agriculture which refer to the production inputs involved in capital, land, labour and management as factors of production owned by farmers. Balanced activity between production factors and demographics of agricultural areas, including infrastructure in agricultural organizational institutions, is a determinant of the sustainability of agricultural businesses. This balance also serves as an attractive incentive for the regeneration of millennial farmers, as it aligns with their inclination towards technology adoption and problem-solving approaches, contributing to achieving sustainable development goals (SDGs). The fourth factor is the farmer-family dynamics which include all processes related to agricultural life as a whole with the family. Given that agricultural businesses often involve families, it is inevitable that there will be overlapping aspects between work and residence, as well as matters related to finance and resources.

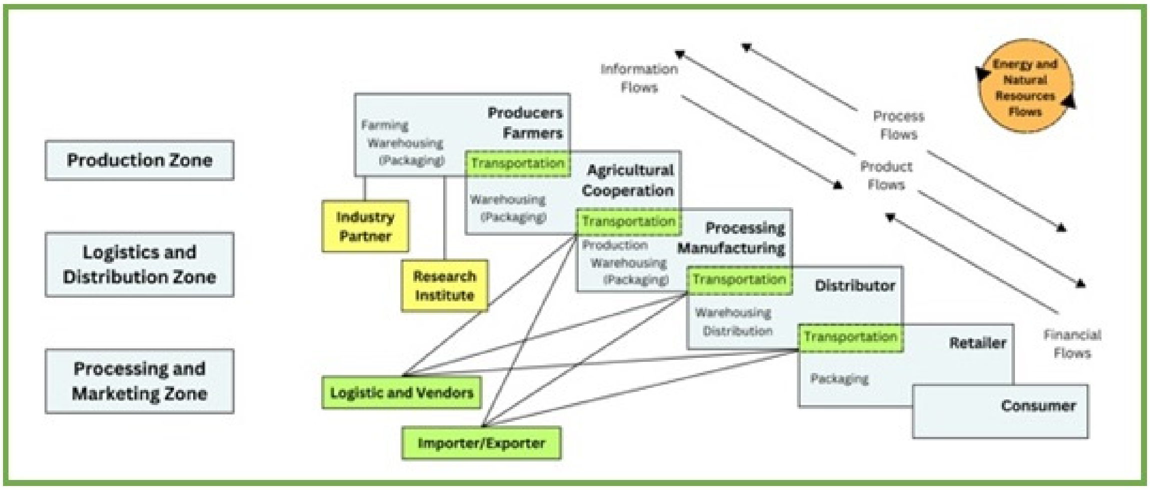

Fig. 3: Supply chain of cocoa Agribusiness in North Luwu Regency

Relationship between farmers' characteristics and adaptive capacity

The correlation coefficient analysis shown in Table 4 provides insights into the relationship between the adaptability of farmers and their characteristics. The characteristics of farmers, specifically the length of agribusiness experience and land area, are related to managerial ability. Land area is positively associated with the technical skills and farmers perceptions of climate change, as well as socio-cultural abilities. Meanwhile, other characteristic variables such as age, education, number of family members, cosmopolitanism, and level of information exposure do not show any significant relationship with the technical, managerial, or socio-cultural adaptability.

According to Shereen *et al.* (2020), the entrepreneurial context in agriculture is shaped by three factors related to agricultural resources and the current circular economy developments. Firstly, the competitive external environment challenges agricultural regeneration, as individuals are enticed by non-agricultural job opportunities that offer higher financial rewards, improved lifestyles, and increased leisure time. Factors such as wage differentials, economic status, and the desire for vacations contribute to this competition. Furthermore, Dhir *et al*. (2021) highlighted the significance of non-agricultural labour market options, access to credit facilities, availability of agricultural inputs, land conditions, prices, and the ability to process raw materials into final products. These factors influence farmers' aspirations to become managers of their agricultural businesses. Secondly, limited knowledge and skills in product processing pose obstacles to the formation of entrepreneurial farmers. Insufficient expertise in processing agricultural products may hinder the development of value-added products and limit opportunities for entrepreneurship among farmers. Thirdly, policy support is crucial to safeguard the potential of human resources as a skilled workforce and reduce dependence on government assistance. It is important to provide accessible behavior change training programs for farmers, fostering an entrepreneurial mindset in agriculture and minimizing off-farm migration. The changes in the biophysical environment of cocoa plants indirectly affect the socio-economic environment of farmers, who are the main stakeholders in cocoa production. These impacts also influence the cocoa trading system in the two regencies. The cocoa trading system begins with farmers and farmers' groups (such as Koptan Masagena) who produce and ferment cocoa beans. These farmers and cooperatives then sell the dry beans to buyers, including the Chalodo Chocolate cocoa bean processing factory, Olam Food Ingredients (OFI) company, and Mars Sustainability company. The companies further process the beans into cocoa flour or final products ready for consumers. Based on Fig. 3 and in accordance with

Table 4: Correlation coefficient between farmers' characteristics and adaptive capacity

Farmers' characteristic	Farmers' adaptive capacity		
	Technical ability	Managerial ability	Socio-cultural ability
1. Age	-0.049	-0.110	-0.072
2. Formal education	-0.026	0.036	0.015
3. Non-formal education	0.012	-0.069	0.040
4. Agribusiness experience	0.057	- 0.137*	-0.072
5. Land area	-0.127*	0.133**	0.040
6. Number of family members	-0.031	0.029	-0.059
7. Cosmopolitanism	-0.061	-0.072	0.039
8. Information level of exposure	-0.042	-0.112	0.025
9. Farmers perception of climate change	-0.053	-0.039	0.136*

* Has a significant correlation at the level of 0.05
** Has a significant correlation at the level of 0.019

the study by Dhir *et al*. (2021), the cocoa agribusiness supply chain system should be supported by a policy framework that covers both upstream and downstream processes. The supply chain system can be divided into 3 zones, including 1) Production zone encompasses agricultural production, including cultivation, product processing, warehousing, and packaging. The key actors involved in this zone are farmers, partners/companies/vendors providing facilities and infrastructure, industrial processing companies, and research institutions. 2) Logistics and distribution zones bridge the production zone, facilities and infrastructure providers, processing industries, and consumers. Logistics companies play a crucial role in effectively planning, implementing, and supervising the transportation process of goods or services, energy, and other resources from the point of origin to the point of use. They work closely with suppliers or logistics vendor companies. 3) Processing and marketing zone encompasses production, warehousing, and packaging activities. The main actors in this zone are processing companies, suppliers of raw materials and supporting materials, logistics companies and vendors, as well as importers/exporters.

Farmers in North Luwu Regency showed superior managerial abilities in handling their farming business finances and keeping detailed records of income and expenditures compared to those in Luwu Regency. This finding is supported by studies highlighting the significance of managerial skills for cocoa farmers in understanding and adapting to changes in the farming environment (Sianipar, 2022; Asante *et al.,* 2022). Farmers need to possess inherent capacities and a strategic management mindset, similar to business managers, enabling them to predict and address challenges arising from the farming environment. This was in accordance with the study by (Mbow *et al.,* 2014; Prain *et al.,* 2020), which emphasized the role of Non-Governmental Organizations (NGOs) in developing the managerial capabilities of farmers through personality and farming management training, participatory decision-making, empowerment, and community capacity building. These efforts aim to strengthen the relationship between farmers and markets while fostering rural development. Buitenhuis *et al*. (2020) stated that the prevalence of high socio-cultural abilities within a society or specific segments instilled hope for improved capabilities and trust in innovation. In both regencies, the socio-cultural abilities remained high, thereby facilitating the development of enhanced adaptive capacities among farmers through collaborative efforts within institutions. Farmers also exhibit substantial social capital, which promotes the coordination and development of institutions. Some important factors in enhancing the capacity of rice farmers include their active involvement, partnerships, the adoption of innovative practices and technology transfer, social capital, and access to business capital (Idawati *et al.,* 2018). The age range observed in this study shows that cocoa agribusiness activities can be optimally carried out with the available physical labour, and farmers still possess significant enthusiasm for agricultural activities. (Giovanopoulou *et al.,* 2011) showed a statistically significant positive correlation between age and adopting good agricultural practices, highlighting the greater effectiveness of young and productive farmers in implementing such practices. Despite cocoa experts in the area, motivating farming communities to replant cocoa trees has proven challenging. Therefore, efforts should be made to enhance the capacity of individual farmers through knowledge acquisition, attitudinal development, critical awareness, and skill building (Jallow *et al.,* 2017). The perceptions of farmers show limited information regarding the impacts of climate change and the support provided by government policies for the sustainability of cocoa agribusiness (Hirons *et al.,* 2018). Non-formal education plays a crucial role in influencing the ability of farmers to develop their agribusiness and stay abreast of advancements in agricultural technology influenced by local practices. It has been proven that educational factors, specifically non-formal education, heavily influence adoption of new technologies and the dissemination of extension information.

Adaptive capacity of farmers in overcoming climate change impacts

Technical ability

Technical adaptation is essential for successful cocoa cultivation, particularly when facing challenges such as climate change. To overcome the impact of the rainy season, farmers must focus on frequent harvesting, regular pruning, the use of shade trees, and following the cacao growing season calendar. During the rainy season, farmers must diligently prune cocoa plants and shade trees to reduce moisture. Similarly, they should ensure a water source for their cocoa fields during the dry season to prevent issues such as flower dropping, wilting, and plant death. Some farmers lack discipline in implementing these practices, but those who devote their time and effort to cocoa agribusiness and diligently care for their farms enjoy a prosperous period with high income. Technical skills are acquired through intentional, systematic, and continuous effort, enabling farmers to perform well in managing cocoa cultivation. As a significant environmental factor, climate greatly influences various stages of cocoa cultivation, such as land preparation, seed selection, flushing, flowering, fertilizing, pruning, harvesting, and post-harvesting. Cocoa plants thrive in conditions with a moderately distributed and consistent combination of temperature, humidity and rainfall throughout the year. Therefore, it is crucial to employ cocoa cultivation techniques that are adaptive to climate change. The strategic positioning of cocoa plantations in open areas allows maximum sunlight penetration, facilitating renewable energy generation through optimal photovoltaic panels (Naderipour *et al.*, 2020). This renewable energy can be used to improve the irrigation system of cocoa plants efficiently. Water pumps powered by photovoltaic energy, equipped with a meta-heuristic Intelligent Water Drops Algorithm (IWDA), can effectively supply water in remote areas (Naderipour *et al*., 2021). Widespread implementation of this innovation has the potential to increase cocoa plantation productivity. The decreasing cocoa yield in Luwu Regency is attributed to the shrinking cocoa plantation area caused by farmers rejuvenating cocoa plants or converting land for seasonal or other plantation crops. The conversion of cocoa fields into rainfed rice fields through government programs is prevalent due to decreased cocoa productivity primarily caused by increased pest attacks, which are associated with the low adaptive level of farmers in plant care. Adaptive level refers to the technical ability of farmers to adjust their farming practices based on the cacao cultivation calendar when faced with climate change. For instance, during the rainy season, characterized by high rainfall, adaptive farmers prune cocoa plants and shade trees to prevent moisture accumulation, which can lead to pest and disease development (Karpouzoglou *et al.*, 2016).

Managerial ability

Farmers in North Luwu Regency exhibit superior managerial skills compared to their counterparts in Luwu Regency. They show competence in financial management and allocate sufficient working capital for their agribusiness operations. To enhance the managerial capabilities of farmers, assistance from NGOs is essential. This support can be provided through personality development and agribusiness management training, emancipatory participation, empowerment, and community capacity building. These initiatives aim to strengthen the relationship between farmers and markets and promote rural development (Kosoe & Ahmed, 2022). It has been observed that the income of farmers from cocoa farming positively impacts their managerial abilities, as higher income generates better business planning outcomes, particularly in terms of input support and resulting production output. This finding aligned with the study conducted by Ayanlade *et al.* (2018), which highlighted the significant influence of capital and production facilities on the planning of fish farming businesses. Access to capital also influences business development, as greater capital resources contribute to improved managerial decision-making in using funds for business management. To enhance financial management efficiency and reliability among farmers, it is advisable for farmers' organizations, in collaboration with partners, to introduce modules that assist farmers in managing their finances effectively. Local companion organizations can collaborate with banks or institutions experienced in financial management at the district or village level to facilitate this process. According to Meuwissen *et al.* (2019), adaptive cycle processes, encompassing agricultural practices, regional demography, risk management, and governance, are integral components of a managerial system that shapes the adaptive frameworks of farmers within agricultural resilience systems.

Socio-cultural ability

Socio-cultural abilities facilitate collaboration and connection among individuals, groups, communities, organizations, and society. Farmers possess the ability to collaborate in developing their farming businesses and search for information from various sources such as the government, partnerships, and the general public. In a constantly changing society, it is important to recognize that society should not be viewed as a fixed state but as an ongoing process or a continuous flow of events without interruption. Society, including groups, communities, organizations, nations, and countries, is contingent upon actions, changes, and perpetual processes within it (Tschora and Cherubini, 2020). The socio-cultural capabilities of cocoa farmers, specifically their ingrained habits and persistent behaviors, significantly influence the development of farming practices (Schroth *et al.,* 2016). Farmers continuously strive to enhance their farming businesses through intensified efforts. A notable indicator of this intensification is the deliberate selection of plant species with high economic value based on agroecological conditions and land suitability (Karpouzoglou *et al*., 2016). Cocoon farmers maintain high expectations in both Luwu and North Luwu Regencies, and their socio-cultural abilities fall within the high category. These regions exhibit social capital capabilities characterized by trust in extension workers, which enables active participation in development meetings. Adaptation, effective farming management, and institutional structures play significant roles, guided by socio-cultural values and community outreach abilities (Lobley & Potter, 2004). According to Meuwissen *et al*. (2019), ensuring the economic, social, and ecological sustainability of agricultural systems in Europe necessitates proactive engagement from agricultural actors, supply chain stakeholders in the circular economy, farmers' institutions and organizations, and the availability of relevant products and services. These efforts aim to address agricultural and environmental challenges within a regional context while upholding the resilience of agricultural systems. This entails harnessing the functions and systems that facilitate economic problem-solving, climate-related concerns, and environmental factors. Moreover, the evolving landscape of farmers' institutions calls for increased adaptability and the adoption of transformative technologies.

Relationship between farmers' characteristics and adaptive capacity

The cocoa agribusiness industry requires advanced technical skills due to its complex nature. Small land holdings and intricate challenges make it crucial for farmers to possess the expertise to maximize their income. The heightened awareness regarding climate change impacts public willingness to interact and collaborate with farmers' groups and the broader community. The ability of a group or community to withstand and overcome challenges in the farming environment, known as individual resilience, is influenced by cultural characteristics. This resilience empowers farmers to prioritize information exchange within their community, enabling them to develop their knowledge and skills. It also involves using regional local wisdom for technology transfer, fostering institutional development and partnerships, as well as leveraging the social capital and role of society (Idawati *et al.,* 2018; Adger, 2000; Idawati *et al.,* 2019). Developing human resources through technical knowledge alone is insufficient to address the problems of farmers.

It requires the involvement of stakeholders from multiple sectors in a sustainable manner. Problem-solving involves identifying the sources of problems, offering technical solutions, and integrating farm management skills, planning, control, evaluation, and socio-cultural approaches. This step aims to modify the behavior of rural communities, which hold deep attachments to their local customs and culture. It is an adaptive action that considers the cultural, social, and economic conditions of the target innovation area. Agriculture is a way of life, profession, and lifestyle for farmers within local communities and the broader agricultural context. The public perception regarding the future of farmers due to negative information portrayed by the media, emphasizing their dependence on nature and climate, need to change. Additionally, the increasing emphasis on big data in the global landscape has shifted the expectations of people and reduced the attractiveness of agricultural professions. This perception is exacerbated by the minimal profits receive from operations compared to large processing factories that source their raw materials. The lifestyle connotations associated with rural farming, such as lack of leisure time and unbalanced work hours, further discourage individuals from pursuing careers in agriculture. The attractiveness of agriculture in rural areas is crucial for the next generation of farmers. It heavily relies on the appeal of agricultural locations and their natural resources, which are determined by the accessibility and quality of essential infrastructure and services, including education. Enhancing the promotion of rural villages and creating a sense of comfort and peace in natural surroundings are essential for both residents and visitors to rural areas.

CONCLUSION

In conclusion, the characteristics of farmers in the two regencies showed similarities in age, non-formal education, number of dependents, and their perception of climate. Differences were observed in terms of formal education, years of experience in agribusiness, land area, cosmopolitanism, and level of information exposure. Farmers with larger land holdings required higher levels of managerial adaptability, but their technical abilities tended to be lower. The length of agribusiness experience did not necessarily lead to improved managerial adaptability. Conversely, farmers with stronger socio-cultural abilities had a more positive perception of the impact of climate change. The adaptive capacity of cocoa farmers is directly influenced by internal factors, including non-formal education and years of farming experience, affecting their technical, managerial, and socio-cultural abilities. The technical adaptive ability of farmers involves practices such as regular measurement of soil pH, use of organic fertilizers, biannual soil liming, manual weed clearance (without herbicides), and proper disposal of cocoa shells. Farmers should adopt a) cocoa Good Agricultural Practices (GAP), b) water-saving technologies, c) participate in Climate Field Schools and Integrated Pest Management Field Schools, d) establish demonstration plots/ gardens, e) implement crop diversification through agroforestry, and f) develop a climate adaptation cacao cultivation calendar. The adaptive managerial ability of farmers, particularly in determining the quantity and pricing of inputs, as well as keeping records of production costs, was found to be very low. Planning, farming knowledge, and cost recording were lacking among most farmers, leading to increasing production costs and insufficient income to meet their family and business capital needs. Farmers mostly relied on estimations and information from fellow farmers who employed similar practices. The strength of social capital within the farming community played a crucial role in fostering trust among farmers, extension workers, and stakeholders. It also promoted tolerance among residents and the adherence to customary rules for adaptive environmental management, thereby supporting sustainable cocoa farming. Sustainable cocoa farming entails increased income and independence for farmers and their groups, environmental sustainability, and farmers' regeneration. This can be achieved through a) increased income and independence of farmers, environmental sustainability and regeneration through efforts to ensure the implementation of the counselling, b) the institutional activity of cocoa farmers' groups as a vehicle for learning and c) government support in terms of infrastructure and facilities. Collaboration with the Meteorology, Climatology, and Geophysics Agency (BMKG) and extension agents can be beneficial, along with providing adequate water sources, drainage systems and enhancing the skills of extension agents to cater to the specific needs of the superior commodities of the target areas. It is important to provide guidance, monitoring, and ongoing evaluation, beyond mere subsidies to enable farmers to focus professionally on their commodities. Implementing counselling based on needs, fostering active organizations in rural areas, and fulfilling cocoa infrastructure are key strategies to achieve these objectives.

AUTHOR CONTRIBUTIONS

Idawati conducted a thorough literature review, designed the study, supervised the experimental work, and drafted the manuscript. N.A. Sasongko played a key role in conceptualizing the study, designing the study, interpreting the data, supervising all experiments, and contributing to manuscript preparation. A.D. Santoso contributed to the literature review, supported data collection, validated data, conducted statistical analysis, and edited the manuscript. M. Septiani supported data collection, validation, and graphing maps and figures. T. Handayani contributed to data collection, validation, analysis, interpretation, manuscript preparation, and graphing maps and figures. A.Y.N. Sakti conducted the literature review, supported experimental and administrative work, and offered technical and material assistance. B.D. Purnamasari performed the literature review, supported experimental and administrative work and provided technical and material assistance. A. Albahry performed the literature review, supported experimental and administrative work and provided technical and material assistance.

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CONFLICT OF INTEREST

The author declares no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication/falsification, double publication/submission, and redundancy, have been completely observed by the authors.

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ABBREVIATIONS

%	Percent
AGS	Aerobic granular sludge
BMKG	Badan meteorology klimatologi, dan geofisika (meteorological, climatological, and geophysical agency of Indonesia)
FAO	Food and agricultural organization
GAP	Good agriculture practices
IWDA	Intelligent water drops algorithm
kg/ha/y	Kilogram per hectare per year
m	Meter
mm	Mili meter
NL	North latitude
NGOs	Non-governmental organization
OFI	Olam Food Ingredients
P	Phosphate

P3SP	Harvesting, pruning, plant-disturbing organisme control, fertilizing, and sanitation
PPO	Plant pest organisme
SDGs	Sustainable development goals
SFITAL	Sustainable farming in tropical Asian landscape
SL	South latitude
SLI	Climate fiels schools
SLPHT	Integrated pest management field schools
SPSS	Statistical analysis in social science
y	Year

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