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REVIEW PAPER

Climate change impacts, adaptation and mitigation in the agricultural sector

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ABSTRACT

The current study provides a comprehensive analysis of climate change adaptation and mitigation in Indonesia's agricultural industry, addressing a significant research gap. By classifying approaches into ecological, economic, and social aspects, it presents valuable information for decision-makers and industry professionals. The review reveals an increasing interest in climate change adaptation and mitigation research between 2016 and 2021, with a subsequent decrease from 2021 to 2023.The majority of research is centered on crop farming, accounting for 60 percent of the studies conducted. The primary areas of study are concentrated in Java, which is a crucial region for crop production, making up 46 percent of the research locations. The sub-sectors examined include crop farming and fisheries. Ecological adaptation in crop farming involves technology adoption, intensive farming management, environmentally friendly agriculture, cropping pattern and timing adjustments, water management, superior varieties, and crop diversification. Within the realm of fisheries, ecological adaptation involves embracing new technology, modifying fishing schedules, and shifting fishing locations. Economic adaptation strategies encompass household consumption reduction, access to credit and insurance, livelihood diversification, asset selling, and savings utilization. Social adaptation encompasses utilizing indigenous knowledge, enhancing interpersonal connections, and supporting agricultural or fishing communities. The study delves into socioeconomic factors influencing adaptation and mitigation to climate change impacts, including individual characteristics, resource access, and institutional involvement. Farmers' ability to adapt is greatly influenced by factors such as gender, education, and access to resources. It is important to consider that while adapting and mitigating climate change may involve temporary drawbacks like decreased productivity and initial financial burdens, the long-term advantages for small-scale farmers are substantial, including improved well-being and increased resilience. This study aids in identifying adaptation and mitigation strategies to guide farmers and policymakers in reducing risks and building resilience within the agricultural system. Limitations in Indonesian studies, particularly outside Java, and the focus on fisheries and livestock sub-sectors provide opportunities for further research. It enhances the academic impact on the progression of knowledge growth in the field of climate change adaptation and mitigation within the agricultural industry of Indonesia.

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105

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2

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INTRODUCTION

Climate change significantly impacts the agricultural sector, including variability in rainfall patterns, rainy days, extreme temperatures, and wind speed. Climate change acts as a constraint on agricultural activities and generates a multiplier effect on decreased productivity, increased farming risks, household vulnerability, food insecurity, and poverty (Wossen *et al.*, 2018; Kogo, *et al.*, 2021; Malau *et al.*, 2021; Sam *et al.*, 2021; Tadesse *et al.*, 2021; Suranny *et al.*, 2022). Farmers' awareness of climate change and the necessity for adaptation stems from their heavy reliance on climatic conditions (Abidoye *et al.*, 2017). Adopting and implementing strategies for adaptation and mitigation lead to numerous beneficial outcomes, such as a boost in overall revenue (Ahmad and Afzal, 2020), improve welfare (Mujeyi *et al.*, 2021; Rahman *et al.*, 2023), and food security (Murniati *et al.*, 2019; Diallo *et al.*, 2020; Mulwa and Visser, 2020; Rahman *et al.*, 2021). Understanding climate fluctuations is essential for the long-term viability of the agricultural industry and for guaranteeing a sufficient food source for an expanding populace (Anderson *et al.*, 2020). By the year 2050, it is projected that the global population will reach 9.7 billion, indicating a significant increase of 1.7 billion individuals compared to the population documented in 2023 (Sadigov, 2022). Ironically, climate change exacerbates the difficulty of ensuring adequate food supply as agricultural productivity diminishes, reducing food adequacy and quantity (Malhi *et al.*, 2021). The exploration of climate change adaptation and mitigation (CCAM) in literature has covered numerous regions, namely Nigeria (Onyeneke *et al.*, 2019), Pakistan (Saddique *et al.*, 2022), South Asia (Aryal *et al.*, 2020), Africa (Akinnagbe and Irohibe, 2014; El Chami *et al.*, 2022), and Nordic (Wiréhn, 2018). Indonesia, a nation primarily reliant on agriculture, has not been the subject of any research thus far. The agricultural industry in Indonesia accounts for 13.22 percent (%) of the gross domestic product (GDP) and employs 29% of the population. Smallholder farmers play a crucial role in this sector, facing challenges such as financial limitations and susceptibility to market price changes (Aguilar *et al.*, 2022). Changes in the climate, such as unpredictable rainfall or rising temperatures, have the potential to cause significant disruptions to production processes (Irham *et al.*, 2018). They are often more vulnerable to these changes compared to largeholder farming. Farmers in Indonesia agree that climate change is leading to reduced production (Evizal and Prasmatiwi, 2021). Farmers feel climate change impacts through increasing temperatures, reducing rainfall, and increasing pests and diseases (Tripathi and Mishra, 2017; Paudel *et al.*, 2020; Saptutyningsih *et al.*, 2020). Surmaini *et al.* (2023) indicate the correlation between climate variability and increasing pest attacks, which damage the rice cultivation areas in Indonesia. Hasibuan *et al.* (2023) state that climate change has influenced the use of fertilizer and pesticides. Suminah and Anantanyu (2023) highlight the diminishing reliability of traditional local wisdom in anticipating climate change. It implies that the traditional farming practices, which have historically relied on indigenous knowledge, may not be sufficient to adapt to the rapidly changing climatic conditions. Evizal and Prasmatiwi (2021) suggest that farmers in Indonesia acknowledge the impact of climate change, which subsequently results in reduced agricultural production. Budiman *et al.* (2020) conducted a study indicating that climate change has led to agricultural production losses ranging from 5% to 20% in Indonesia. Firmansyah *et al.* (2022) highlight the impact of high El Nino (abnormally warm ocean temperatures in the central and eastern tropical Pacific Ocean) on agricultural productivity, resulting in decreased annual rainfall levels and high La Nina (abnormally cold ocean temperatures in the same region) leading to increased rainfall. The researchers also note that extreme rain events and drought conditions decrease productivity (Susilo *et al.*, 2013; Ismail and Chan, 2020; Estiningtyas *et al.*, 2021). This study assessed how farmers adopt CCAM strategies and reduce vulnerability. Despite the extensive understanding of CCAM, there is a significant dearth of thorough literature reviews that specifically concentrate on CCAM in Indonesia's agricultural industry. This sector plays a crucial role in the country's economy and people's livelihoods. This study conducts a systematic review to fill a gap in understanding CCAM in Indonesia's agricultural sector. It categorizes adaptation strategies into ecological, economic, and social dimensions, providing insights for stakeholders to develop tailored strategies. The study endeavors to enhance environmental sustainability, economic prosperity, and social resilience in the face of climate uncertainty by thoroughly examining these aspects. It not only adds to academic knowledge but also provides valuable insights for policymakers and agricultural practitioners, guiding them in developing

Table 1: Criteria for acceptance and rejection

Search Criteria	Acceptance criteria	Rejection criteria
Initial search	English language	Non-English languages
	CCAM	Non-CCAM
	Agricultural sector	Non-agricultural sector
	Focus in Indonesia	Other countries
	Research article	Non-research article
	Period in 2010-2023	Outside period 2010-2023
Title and abstract	Agricultural sectors	Non-agricultural sectors
	Smallholder farming	Large scale farming

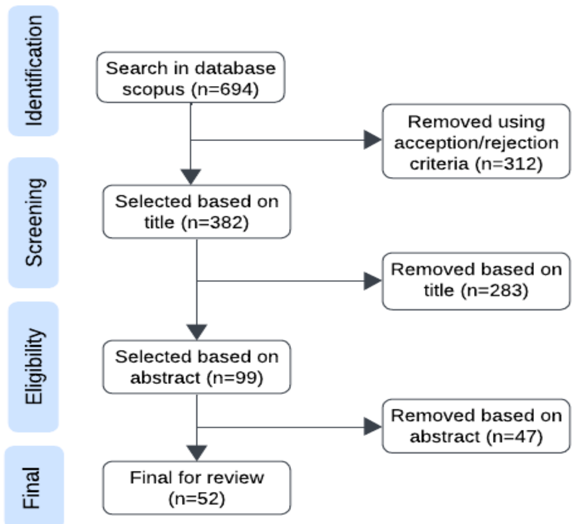

Fig. 1: The literature selection process

efficient adaptation strategies. The findings inform future research, policy formulation, and community engagement initiatives to promote sustainable farming practices and enhance rural well-being. The aims of the current study are 1) to identify CCAM practices in the Indonesian agricultural sector and 2) to categorize CCAM based on ecological, economic, and social aspects. The current study is carried out by searching for documents in the Scopus database and summarizing the findings and was conducted in 2024 through an in-depth examination of research on CCAM in the Indonesian agricultural sector from 2010-2023.

MATERIALS AND METHODS

The present research was conducted by reviewing a thorough search and careful selection of literature on CCAM. The categorization of CCAM into ecological, economic, and social adaptation was based on previous studies by Owen (2020) and Suadi *et al*. (2022). To ensure the clarity and precision of the literature search, the study employed the widely recognized Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. This framework has been extensively utilized in climate change reviews, as demonstrated by studies conducted by Onyeneke *et al*. (2019), Malhi *et al*. (2021), Diana *et al*. (2022), Saddique *et al*. (2022), and Tasevska *et al*. (2023). The research focused on CCAM in the Indonesian agricultural sector and utilized the Scopus database to search for relevant literature from 2010 to 2023. Table 1 outlines the criteria for accepting and rejecting literature, which was implemented to enhance the accuracy of the search process.

RESULTS AND DISCUSSIONS

Upon conducting the initial literature search, a total of 694 documents were obtained. However, after carefully evaluating the acceptance and rejection criteria, the final result consisted of 52 documents. These documents were sourced from various scholarly sources, including journals (48%), conference proceedings (50%), and book chapters (2%), as illustrated in Fig. 1.

The review results indicate that studies on CCAM began in 2016 and increased until 2021. Furthermore, CCAM studies experienced a decline from 2021 until 2023, as presented in Fig. 2.

Fig. 3 presents the predominant focus of most studies, which is crop farming (60%). This includes food crops, plantation, and horticulture. However, it is worth noting that there is a lack of specific research in the livestock sub-sector. This highlights the necessity for additional research in this particular area.

Based on locations, the research primarily focuses

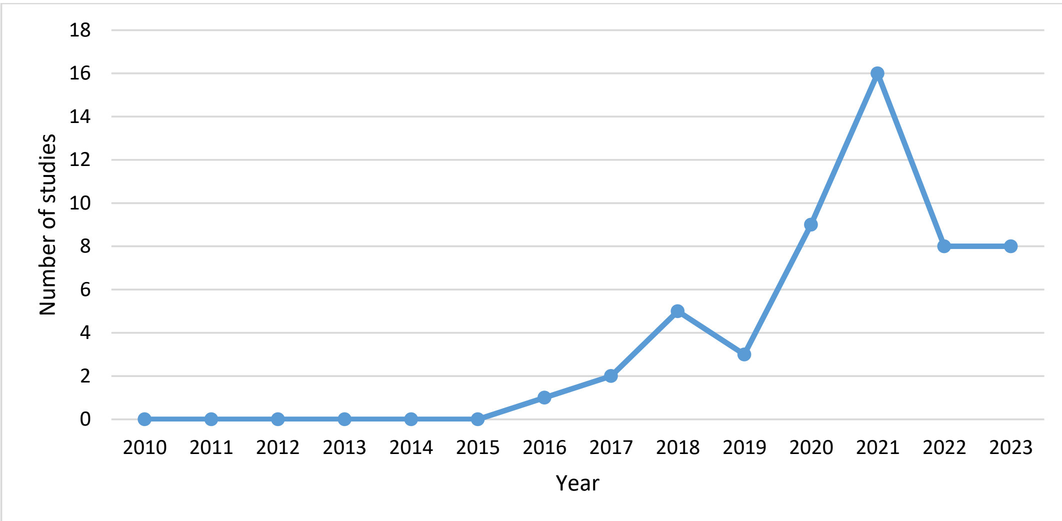

Fig. 2: Number of CCAM studies in the Indonesian agricultural sector

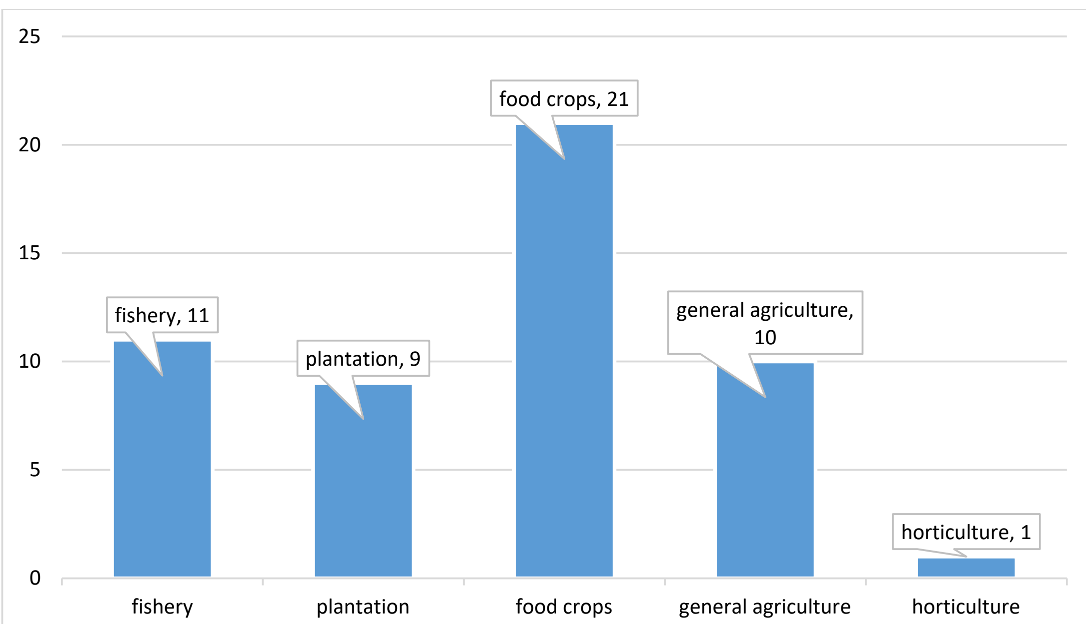

Fig. 3: Focus of study on CCAM in the Indonesian agricultural sector

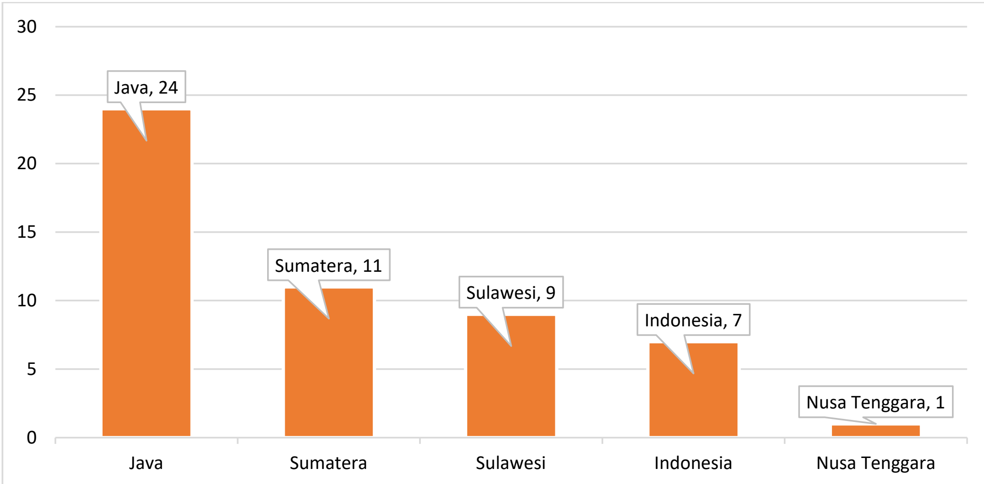

Fig. 4: Study location for CCAM in the Indonesian agricultural sector

on the Java area (46%), and the rest came from other regions, as depicted in Fig. 4. The Java area serves as the primary focus of the study, being the epicenter of food production in Indonesia (Widiatmaka *et al.*, 2016; Rondhi *et al.*, 2018; Estiningtyas *et al.*, 2021). The limited number of studies from Kalimantan, Nusa Tenggara, and eastern Indonesia offers a chance for additional research advancement.

A detailed review of 52 documents revealed various CCAMs in smallholder farming. The adaptation is categorized into two divisions of the agriculture sub-sector: crop farming and fisheries, as detailed in Table 2. Various classifications are used to categorize agricultural activities, taking into account different types of farming practices that necessitate distinct adaptation strategies (Nguyen *et al.*, 2016).

The research offers in-depth analysis of the ecological, economic, and social dimensions of CCAM. It underscores the interdependence of these dimensions, underscoring the influence of climate change on crop yields (ecological), which in turn affects farmers' financial well-being and community cohesion (economic and social). A comprehensive strategy encompassing all these aspects guarantees the economic efficiency, environmental durability, and social integration of agriculture. This is of utmost importance in constructing resilient farming systems that can effectively address forthcoming climate adversities.

Crop farming

In the crop farming subsector, there are 41 documents discussing CCAM, covering various categories, including food crops (rice, maize, and cassava), horticulture (potato), and plantations (palm oil, cocoa, pepper, and tobacco). Rising temperatures have the potential to decrease the productivity of food crops and alter the timing of harvests. Additionally, shifts in rainfall patterns and the intensity of extreme precipitation events can result in floods, which can disrupt food crop production. Moreover, water scarcity poses a significant obstacle to plant growth. Furthermore, climate change has the potential to alter the distribution patterns of pests and plant diseases, potentially intensifying their impact and causing damage to crops.

Ecological adaptation

Ecological adaptation involves farmers responding to the impacts of climate change on agricultural ecosystems, including maintaining biodiversity, preserving soil and water, and sustaining natural resources. Types of ecological adaptation and the percentage of documents are presented in Fig. 5.

Technology adoption

Embracing technology and data offers ease and creativity for farmers in overseeing and enhancing agricultural properties. Setiawan *et al.* (2022)

Table 2: Research on CCAM in Indonesia

No.	Field study	Location	CCAM			Source
			Ecological	Economy	Social	
1.	Plantation	Java	V			Hasibuan *et al.* (2023)
2.	Horticulture	Java	V			Purwanti *et al.* (2023)
3.	General agriculture	Java	V			Anshori *et al.* (2023)
4.	Food crop	Java	V		V	Suminah and Anantanyu (2023)
5.	Food crop	Indonesia	V	V		Massagony *et al.* (2023)
6.	Food crop	Sulawesi	V	V	V	Arifah *et al.* (2022)
7.	Food crop	Sumatera	V	V	V	Mulyasari *et al.* (2022)
8.	Food crop	Java	V			Rahayu *et al.* (2022)
9.	General agriculture	Sulawesi	V			Aguilar *et al.* (2022)
10.	Food crop	Sumatera	V			Heriansyah *et al.* (2022)
11.	Plantation	Java	V			Setiawan *et al.* (2022)
12.	Food crop	Java	V			Wulansari *et al.* (2022)
13.	Food crop	Java		V		Kusumaningrum *et al.* (2021)
14.	Food crop	Indonesia	V			Widyawati *et al.* (2021)
15.	Food crop	Sulawesi	V			Winarno *et al.* (2021)
16.	Plantation	Sulawesi	V			Jumiyati *et al.* (2021)
17.	Food crop	Java	V			Connor *et al.* (2021)
18.	Plantation	Sumatera	V			Evizal and Prasmatiwi (2021)
19.	Plantation	Sumatera	V			Irawan (2021)
20.	Food crop	Sulawesi	V		V	Busthanul *et al.* (2020)
21.	Plantation	Sumatera	V			Utami *et al.* (2020)
22.	Food crop	Java			V	Priswita *et al.* (2020)
23.	General agriculture	Java		V		Budiman *et al.* (2020)
24.	Food crop	Java	V			Barokah *et al.* (2020)
25.	General agriculture	Sulawesi	V	V	V	Rahayu and Suwitra (2020)
26.	Food crop	Sumatera	V			Murniati *et al.* (2019)
27.	Plantation	Sumatera	V			Irawan and Syakir (2019)
28.	Food crop	Java		V		Dewi *et al.* (2018)
29.	Food crop	Java	V		V	Idawati *et al.* (2018)
30.	Food crop	Java	V			Sugihardjo *et al.* (2018)
31.	General agriculture	Indonesia	V			Abidoye *et al.* (2017)
32.	General agriculture	Indonesia	V			Reed *et al.* (2017)
33.	Food crop	Indonesia	V			Yulianti *et al.* (2016)
34.	General agriculture	Java	V	V		Sekaranom *et al.* (2021)
35.	General agriculture	Java		V		Suryanto *et al.* (2020)
36.	Food crop	Sulawesi	V	V		Saediman *et al.* (2021)
37.	General agriculture	Indonesia	V			Apriyana *et al.* (2021)
38.	Food crop	Sumatera	V			Dulbari *et al.* (2021)
39.	Plantation	Java	V			Djufry and Wulandari (2021)
40.	General agriculture	Java	V			Irham *et al.* (2018)
41.	Plantation	Indonesia	V			Muslihah *et al.* (2020)
42.	Fishery	Sulawesi	V			Maharja *et al.* (2023)
43.	Fishery	Java	V			Rahman *et al.* (2023)
44.	Fishery	Sumatera	V			Chan *et al.* (2023)
45.	Fishery	Sulawesi	V	V	V	Suadi *et al.* (2022)
46.	Fishery	Java	V		V	Hafsaridewi *et al.* (2021)
47.	Fishery	Java		V		Hidayati *et al.* (2021)
48.	Fishery	Java	V	V	V	Mulyasari *et al.* (2021)
49.	Fishery	Sumatera	V	V	V	Rusdiyana *et al.* (2020)
50.	Fishery	Nusa Tenggara		V		Paulus *et al.* (2019)
51.	Fishery	Sumatera	V	V	V	Mulyasari *et al.* (2018)
52.	Fishery	Java	V	V		Susilo *et al.* (2021)

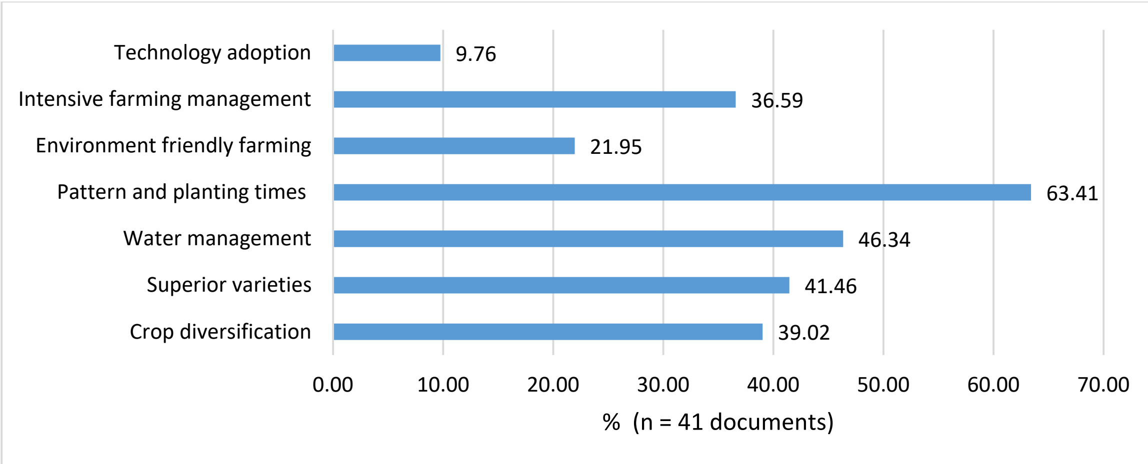

Fig. 5: Ecological adaptation of crop farming

delve into the utilization of advanced agricultural technology to assist farmers in monitoring weather patterns and forecasting upcoming rainy seasons prior to commencing planting activities. Technology adoption with agricultural machinery also facilitates farming activities (Sekaranom *et al.*, 2021). The utilization of agricultural machinery and tools allows farmers to enhance their productivity and efficiency, while also decreasing their reliance on manual labor. The adoption of agricultural technology has proven to increase farmers' income and quality of life, as well as address issues of poverty and food insecurity in local communities (Connor *et al.*, 2021; Mulugeta and Heshmati, 2023). However, technology adoption in the agricultural sector still faces limited technological access (Connor *et al.*, 2021) and inadequate supporting infrastructure. Farmers also complain about the high cost of adopting technology and the constraint of small and fragmented landholdings (Sekaranom *et al.*, 2021). It is essential for the government and key stakeholders to work together in enhancing access to and supporting infrastructure for the adoption of agricultural technology. Initiatives like offering training and education on agricultural technology, improving infrastructure, and providing technological support to farmers can speed up the shift towards adaptive, efficient, and sustainable agriculture.

Intensive farming management

Intensive farming management optimizes resource use while increasing agricultural productivity and efficiency. This approach involves careful management of inputs such as water, fertilizers, and pesticides to ensure efficiency and sustainability. This form of adaptation encompasses the entire farming process, including pre-cultivation, cultivation, harvest, and post-harvest stages (H.S.P. Rahayu and Suwitra, 2020). Farming management includes setting planting distances according to recommendations (Murniati *et al.*, 2019) and increasing the intensity of land clearing (Rahayu *et al.*, 2022). During the cultivation stage, farming management includes fertilization and disease control (Winarno *et al.*, 2021; Heriansyah *et al.*, 2022), reducing chemical inputs (Murniati *et al.*, 2019), and changing fertilizers (Busthanul *et al.*, 2020; Sekaranom *et al.*, 2021). Farmers' use of fertilizers varies considerably, including organic fertilizers (Irawan, 2021; Anshori *et al.*, 2023), chemical fertilizers (Winarno *et al.*, 2021; Heriansyah *et al.*, 2022), and combinations of both (Hasibuan *et al.*, 2023; Purwanti *et al.*, 2023). Efforts to control weeds, pests, and plant diseases involve using pesticides (Arifah *et al.*, 2022; Purwanti *et al.*, 2023) and herbicides (Hasibuan *et al.*, 2023). Specialized knowledge, skills, and input costs are necessary for intensive farming practices, which can limit farmers from implementing these techniques.

Environment-friendly farming

Environmentally conscious farming seeks to reduce negative environmental effects while simultaneously improving agricultural productivity. Research studies have shown that adopting environmentally friendly farming practices, such as soil conservation, can effectively mitigate these impacts. (Barokah *et al.*, 2020; Jumiyati *et al.*, 2021; Purwanti *et al.*, 2023). The primary objective of soil conservation is to mitigate soil erosion and preserve soil fertility through the implementation of various techniques such as cultivating cover crops, building terraces, and creating straw piles. Additionally, farmers strive to clear land without resorting to slash and burn methods in order to safeguard the environment. (Irawan and Syakir, 2019). Although farmers commonly practice land clearing through slashing and burning to facilitate planting and expedite clearing at a lower cost, it has detrimental effects on the environment (Irawan and Syakir, 2019). Another form of environmentally friendly farming is the utilization of plant residues as animal feed or compost (Irham *et al.*, 2018; Irawan and Syakir, 2019; Irawan, 2021). This measure contributes to the reduction of agricultural waste and the decrease in the usage of chemical fertilizers, while also enhancing soil fertility and quality. It is imperative to provide adequate socialization and training on eco-friendly farming techniques in order to encourage farmers to embrace these practices, thereby promoting sustainable agriculture (Liu and Liu, 2024).

Patterns and planting times

This activity was reported by most studies on CCAM, accounting for 63.41% of all studies reviewed. Establishing planting schedules and timing is advantageous for maximizing plant development, mitigating the effects of severe weather conditions, cutting down on production expenses, and enhancing overall efficiency. This practice empowers farmers to efficiently plan their planting and harvesting activities according to climate and weather forecasts. The majority of farmers rely on a planting calendar system that encompasses valuable details regarding optimal planting schedules and techniques, tailored to climate forecasts, planting patterns, and water accessibility (Sugihardjo *et al.*, 2018). Adapting planting times includes planning, harvesting, and marketing (Idawati *et al.*, 2018). Farmers can also leave the land fallow during specific periods, such as during the dry season (Rahayu *et al.*, 2022; Suminah and Anantanyu, 2023). Determining planting periods can be done through cooperation with the Meteorology, Climatology, and Geophysics Agency to monitor weather forecasts (Sekaranom *et al.*, 2021; Setiawan *et al.*, 2022). Farmers can also hold regular farmer group meetings to strategize planting timing (Setiawan *et al.*, 2022). Farmer associations are essential in providing precise planting timing predictions. For plantation crops, adjusting to planting schedules involves deciding when to replant (Evizal and Prasmatiwi, 2021). In many other countries, smallholder farmers adjust their planting patterns and timing to mitigate the impacts of climate change (Ali and Erenstein, 2017; Belay *et al.*, 2017; Tripathi and Mishra, 2017).

Water management

The constraints in agriculture are the scarce water resources and contamination of clean water, making water management crucial for farming sustainability. Water management encompasses the strategic planning, execution, and optimization of water resource utilization to minimize both wastage and negative ecological consequences. This approach is particularly beneficial for farmers as it aids in mitigating the adverse impacts of climate change, particularly in times of drought. (Winarno *et al.*, 2021; Anshori *et al.*, 2023). Based on reviews, water management can be done in several ways, for example: 1) regulating water usage (Arifah *et al.*, 2022), 2) use of pumps (Irawan, 2021; Mulyasari *et al.*, 2022), and 3) irrigation (Hasibuan *et al.*, 2023; Purwanti *et al.*, 2023). Irrigation infrastructure development enables guaranteed water supply and becomes a determinant for farmers adapting to water scarcity (Aguilar *et al.*, 2022). It is imperative to enhance the knowledge and understanding of farmers when it comes to water management practices in order to instill a sense of motivation and encourage them to embrace these practices. In several studies from other countries, water management has also become a primary focus in CCAM (Yohannes *et al.*, 2017; Boonwichai *et al.*, 2021).

Use of superior varieties

Adopting superior varieties resistant to extreme weather conditions or plant diseases can help farmers cope with climate change. Superior cultivars exhibit enhanced resilience towards environmental stress triggered by severe weather conditions and pest infestations, empowering plants to swiftly acclimate and yield superior harvests, even amidst fluctuating environmental circumstances. The long-term goal of using superior varieties is to increase productivity, efficiency, and farming income (Connor *et al*., 2021). The use of superior varieties among farmers is specific to the needs of farmers and environmental conditions. Some types of superior variety development include climate-tolerant varieties (Hasibuan *et al*., 2023; Suminah and Anantanyu, 2023), pest and disease-resistant varieties (Arifah *et al*., 2022), flood-resistant plant varieties (Heriansyah *et al*., 2022), and drought-resistant varieties (Irham *et al*., 2018; Widyawati *et al*., 2021). Adopting superior varieties has been identified as a crucial measure in mitigating the effects of climate change, as highlighted in various studies (Yila and Resurreccion, 2013; Paudel *et al*., 2020).

Crop diversification

Crop diversification is an essential step in sustainable farming practices and is beneficial in enhancing ecosystem stability, reducing the risk of diseases and pest attacks, and increasing farm productivity. Due to climate change impacts, dependence on one crop can lead to reduced yields or crop losses. Crop diversification leads to a wider range of crops being grown, resulting in a more varied harvest and reducing the risk of a decrease in household income. Utami *et al.* (2020) argue that farmers' motives for diversifying are primarily for income stabilization rather than maximization. Crop diversification can be done in the form of intercropping (Irawan, 2021; Purwanti *et al*., 2022; Rahayu *et al*., 2022), crop rotation (Irham *et al*., 2018), and agroforestry (Muslihah *et al*., 2020; Jumiyati *et al*., 2021). In the case of plantation, crop diversification through mixed cropping or intercropping is a common and effective practice (Arifah *et al*., 2022). Mixed cropping helps farmers maximize land use efficiency and minimize risks associated with monoculture. Intercropping allows more efficient use of space, light, water, and nutrients. These activities provide additional income for farmers while they wait for the main crops to mature (Irawan and Syakir, 2019). Farmers can diversify plantation crops with horticultural crops, food crops, and livestock (Utami *et al*., 2020; Djufry and Wulandari, 2021). Previous research has highlighted the crop diversification that addresses the impacts of climate change (Belay *et al*., 2017; Fadina and Barjolle, 2018; Mulwa and Visser, 2020).

Economic adaptation

Economic adaptation in agriculture aims to strengthen the economic resilience of farmers and communities through the diversification of livelihoods and the reduction of household consumption. Additionally, it involves the establishment of agricultural insurance and inclusive financial systems to effectively manage climate risks. Economic adaptation is driven by decreased household income due to climate vulnerabilities, leading farmers to adjust their livelihoods to meet household needs. The adjustments differ depending on the farmers' abilities and financial situations. An illustration of economic adaptation in crop farming can be found in Fig. 6.

Reducing household consumption

Reducing household consumption is a step taken by households experiencing income decline and difficulty obtaining loans (Budiman *et al*., 2020). There are several methods to decrease household consumption, such as minimizing energy and water usage, reducing food waste, and trimming unnecessary expenses. Engaging in these practices not only promotes a simpler way of life but also contributes to the development of a more economically and ecologically sustainable community.

Credit

Farming households that experience a decreased income often require additional capital to meet household needs or invest in the next planting season. Seeking credit or loans can be crucial for maintaining agricultural activities and livelihoods (Budiman *et al*., 2020; Rahayu and Suwitra, 2020; Sekaranom *et al*., 2021). Obtaining a loan from a financial institution is more accessible for farmers because the loan requirements are manageable, and the interest is not too high (Budiman *et al*., 2020). The provision of credit can assist farmers in running their farming businesses and promote sustainable development in the agricultural sector.

Insurance

Crop insurance is a financial protection to protect farmers from agricultural risks. Insurance aims to

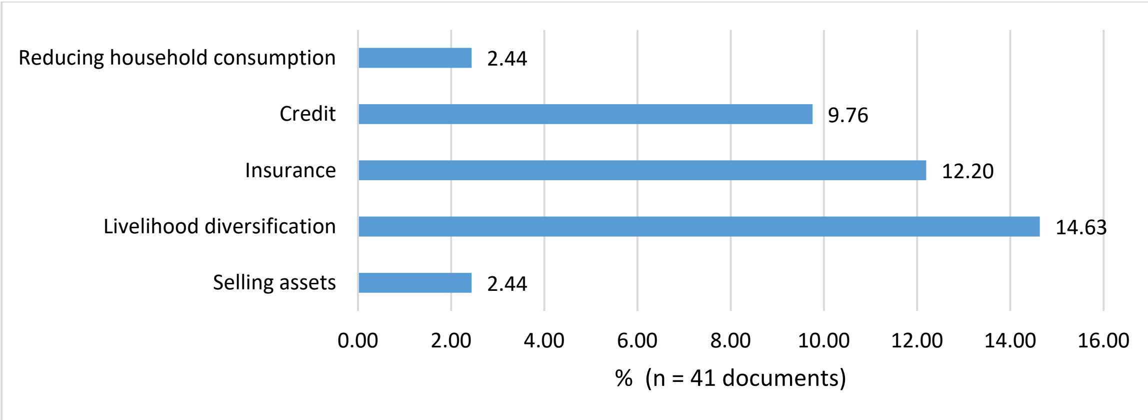

Fig. 6: Economic adaptation of crop farming

offer protection against risks and income stability (Suryanto *et al.*, 2020; Arifah *et al.*, 2022; Massagony *et al.*, 2023). Insurance transfers the risk of loss to another party, and farmers must make premium payments. Crop insurance has become an essential component of the Indonesian government's initiatives to safeguard farmers against the adverse effects of extreme weather, pests, plant diseases, and other potential risks. This form of insurance encompasses a wide range of crops, including rice, corn, soybeans, and vegetables. Challenges in developing insurance include farmers' awareness of insurance benefits, the availability of accurate weather data, and regulations supporting the growth of agricultural insurance. Kusumaningrum *et al.* (2021) proposed integrating crop insurance with "Kredit Usaha Rakyat (KUR)" as a solution to overcome the constraint of premium payments, facilitating easier payment for farmers. Combining crop insurance with financing schemes from the government or financial institutions can reduce economic uncertainty in the agricultural sector.

Livelihood diversification

Livelihood diversification, primarily through non-farm work, is a common strategy adopted by farmers to mitigate risks associated with agriculture and achieve more excellent economic stability (Saediman *et al.*, 2021; Sekaranom *et al.*, 2021; Arifah *et al.*, 2022). Non-agricultural employment is frequently seasonal, particularly during periods of drought. The range of non-farm jobs available to farmers encompasses roles such as traders, construction workers, tailors, and mechanics. This adjustment entails involving family members in both agricultural and non-agricultural tasks (Mulyasari *et al.*, 2022). Individuals benefit from livelihood diversification through developing skills and knowledge in other fields and expanding their network of contacts with other parties.

Selling assets

The adaptation of selling personal assets, such as gold and livestock, is highlighted as the easiest and quickest strategy for farmers to acquire additional capital for farming and to meet household needs (Budiman *et al.*, 2020).

Social adaptation

Social adaptation is deeply ingrained in the innate social tendencies of human beings, recognizing the imperative of fostering cohesion and equilibrium within society. It acknowledges that individuals do not exist in isolation but rather exist as interconnected entities within their communities. Consequently, collaborative endeavors become indispensable in effectively tackling pressing issues like climate change (Hosen *et al.*, 2020). Social adaptation in crop farming is presented in Fig. 7.

Local knowledge

Local knowledge refers to traditional knowledge developed over time within communities and plays a vital role in helping agrarian communities adapt to the impacts of climate change (Arifah *et al.*, 2022). It strengthens local communities' adaptive capacity and

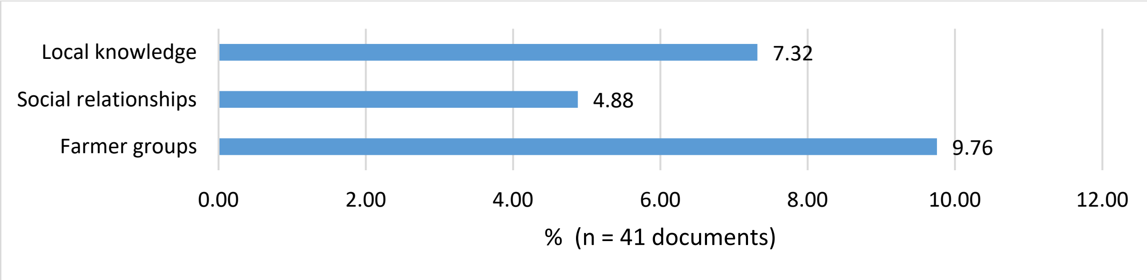

Fig. 7: Social adaptation of crop farming

helps preserve valuable cultural and environmental heritage. An example of traditional wisdom is scheduling planting activities based on the phase of the moon in the sky. During the full moon, farmers avoid planting because it attracts pests (Rahayu and Suwitra, 2020). Sekaranom *et al.* (2021) discuss "pranata mangsa" as local knowledge among farming communities in determining planting times. Singgang is a well-known local practice in rice farming that involves the cultivation of ratoon rice. This unique method is an excellent example of how farmers in the region have adapted their techniques to maximize their rice yields (Priswita *et al.*, 2020). Utilizing local knowledge assists in decision-making for adaptation and mitigation in the agricultural sector (Klenk *et al.*, 2017). Farmers highly value local knowledge because it is practical, personal, and specific to their local context. However, more significant efforts are needed to develop local knowledge (Sumane *et al.*, 2018).

Social relationships

An example of improving village communities' social relationships is "gotong royong" (Busthanul *et al.*, 2020). The benefits obtained from this social relationship are sharing information and finding solutions to every problem. Idawati *et al.* (2018) elucidate the importance of upholding social, cultural, and cooperative principles within agricultural practices. The presence of strong social bonds plays a pivotal role in molding the ability to adapt, enabling communities to effectively confront the obstacles posed by climate change and bolster their resilience.

Farmer groups

Farmer group engagement enhances the effectiveness of Climate Change Adaptation and Mitigation (CCAM) by promoting the exchange of knowledge, mobilizing resources, and fostering capacity development within farming communities. Collaborative efforts within these groups can bolster farmer resilience, sustain livelihoods, and establish agricultural systems that are responsive to climate challenges (Idawati *et al.*, 2018; Suminah and Anantanyu, 2023). Participation in farmer groups is rational and crucial for farmers, especially those with limited education and experience, to enhance their knowledge and access to information. Farming associations assist farmers in accessing government aid, which is frequently offered through complimentary or discounted services and is channeled through the organizations as a whole rather than to individual farmers. This aid encompasses a range of support options, including input subsidies, technical education, financial aid, and insurance programs. Utilizing government assistance through farmer groups is an important strategy to increase CCAM in agriculture, as discussed in previous research (Rahayu and Suwitra, 2020; Mulyasari *et al.*, 2022).

Fisheries subsector

Within the fisheries sub-sector, there are a total of 11 documents that address CCAM. Climate change in the fisheries sub-sector has negative impacts on both economic and cultural aspects, leading to a decline in the welfare of individuals and communities. Economically, climate change affects the decline in fish catches due to increased sea surface temperatures, high waves, and strong winds (Mendenhall *et al.*, 2020; Mandhalika *et al.*, 2021; Chan *et al.*, 2023). The marine ecosystems are being disturbed by these alterations in the environment, which in turn have an impact on the abundance, distribution, and behavior of fish populations, ultimately leading to a decline in the catches made by fishermen. The traditional livelihood of fishermen relies heavily on ecological knowledge to uphold their social identity, so climate change will directly impact the culture of local communities (Maharja *et al.*, 2023). As fishing practices become less productive or viable in changing environmental conditions, these communities may face economic hardships and social dislocation. To tackle these obstacles effectively, it is essential to adopt comprehensive strategies that combine ecological preservation, responsible resource utilization, economic variety, and the safeguarding of indigenous knowledge systems.

Ecological adaptation

In the fisheries sub-sector, ecological adaptation uses marine and other natural resources that support fishing activities. This adaptation varies depending on business characteristics, type of fishing gear, and fishermen's financial capabilities. Ecological adaptation in the fisheries sub-sector is presented in Fig. 8.

Technology adoption

Technology adaptation involves developing and applying technological innovations to assist fishermen in adapting to environmental changes and sea conditions caused by climate change. The review results display technology adoption, including the addition of fishing gear (Suadi *et al.*, 2022), fish finder technology (Mulyasari *et al.*, 2021; Hafsaridewi *et al.*, 2021; Rahman *et al.*, 2023), and using a large boat with size more than 5 Gross tonnage (GT). Large-scale fishermen are more resilient than small-scale fishermen due to their utilization of larger boats (Chan *et al.*, 2023). Technological adoption within fishermen communities is hindered by various constraints such as inadequate access to infrastructure (electricity and communication networks) and the expensive nature of acquiring and upkeeping boats and fishing gear. The steep costs act as a deterrent for fishermen who have limited financial resources, especially when their earnings are impacted by climate change. Additionally, certain fishermen prefer to adhere to traditional fishing methods and are hesitant to experiment with new technologies that they view as potentially risky.

Adjustment of the fishing schedule

Adjusting fishing schedules can help reduce the risk of accidents for fishermen at sea, especially when facing extreme weather or high waves. Fishermen strategically plan their fishing expeditions according to the migration and reproduction cycles of fish in order to maximize their yield. This practice not only helps in avoiding overfishing but also plays a crucial role in preserving the delicate balance of marine ecosystems and securing the long-term sustainability of fisheries. Fishermen typically organize their fishing schedules using a fishing season calendar (Rusdiyana *et al.*, 2020). The fishing season calendar assists in coordinating fishermen's operations and fishing fleets according to weather conditions, fish migration patterns, or applicable management policies. Fishermen can make more informed decisions about their fishing schedules, such as opting for earlier or extended fishing trips, thanks to this advancement (Susilo *et al.*, 2021). (Mulyasari *et al.*, 2021; Rahman *et al.*, 2023). When the weather is favorable, fishing activities can be increased. When the weather worsens and is unfavorable, fishermen can choose not to do fishing activities and rest until the situation is safe (Suadi *et al.*, 2022).

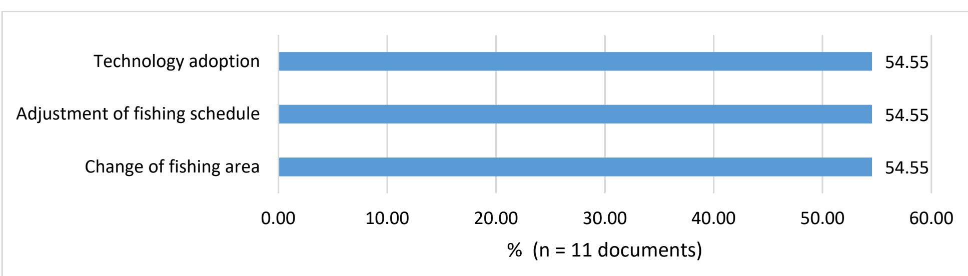

Fig. 8: Ecological adaptation in the fisheries sub-sector in Indonesia

Change of fishing area

The relocation of fishing areas has been reported as one of the CCAMs in many previous studies (Hafsaridewi *et al.*, 2021; Suadi *et al.*, 2022; Rahman *et al.*, 2023). The purpose of relocating fishing grounds is to address the fluctuations in seasons when fish move to particular areas based on factors like water temperature, ocean currents, or feeding habits. In challenging circumstances, like heightened sea waves, fishermen are compelled to shift their fishing grounds and adjust to new locations (Maharja *et al.*, 2023). The benefits of relocating fishing grounds include helping fishermen diversify their catch and reducing pressure on specific species. Recent fishing locations that are more productive can increase fishermen's income and economic well-being.

Economic adaptation

Climate change significantly diminishes the income of fishermen's households, so adjustments are needed to their economic activities. The adjustment of this adaptation caters to the financial capabilities and economic circumstances of fishermen's households. An illustration of economic adaptation within the fisheries sub-sector can be found in Fig. 9.

Reducing household consumption

An effort of CCAM reported in previous studies during a decline in fishermen's income is reducing household consumption, particularly regarding food consumption (Hidayati *et al.*, 2021). A reduction in income resulting from a decrease in fish catches can lead fishermen and their families to make changes in their consumption habits. This may include adjusting both their food and non-food expenditures. For instance, non-food consumption adjustments could entail reducing spending on discretionary items such as clothing, household goods, or entertainment.

Looking for a loan

When fishermen do not have assets or savings, a decrease in household income forces fishermen to seek loans to meet their living needs or as capital for fishing activities. Fishermen can borrow money from relatives or neighbors (Hidayati *et al.*, 2021). Fishermen can also consider microfinance institutions as a source of borrowing with flexible repayment and lower interest rates.

Livelihood diversification

The unpredictable seasons and weather conditions contribute to income uncertainty for fishermen's households. The rising living expenses necessitate fishermen to seek additional income from other jobs, especially during the low season (Mulyasari *et al.*, 2018, 2021; Paulus *et al.*, 2019; Hidayati *et al.*, 2021; Susilo *et al.*, 2021). The type of economic activity can vary according to the fishermen's abilities, for example, by processing fishery products (Rusdiyana *et al.*, 2020; Suadi *et al.*, 2022). Expanding the range of income sources can encompass the entire household, encompassing both spouses and children, thereby potentially enhancing the overall financial resources available to the family (Mulyasari *et al.*, 2018).

Selling assets or using savings

Extreme climate change has the potential to diminish the income of fishermen, compelling them to resort to selling their assets or tapping into their personal savings in order to cover their living expenses and finance their fishing endeavors. The expedient sale of liquid assets, such as boats, fishing

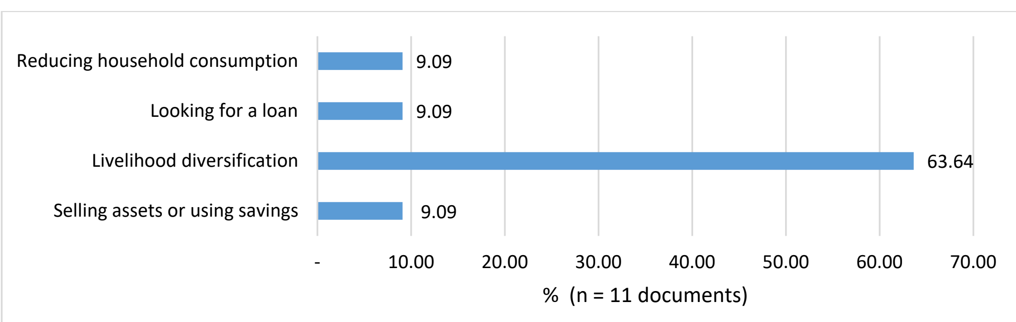

Fig. 9: Economic adaptation in the fisheries sub-sector in Indonesia

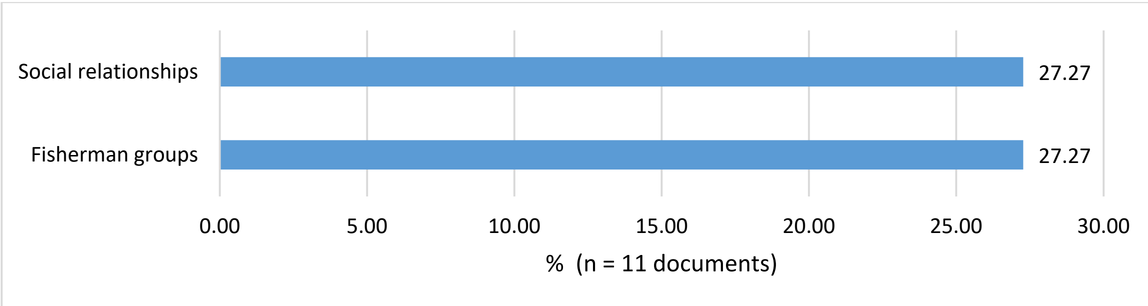

Fig. 10: Social adaptation in the fisheries sub-sector in Indonesia

gear, or other valuable items, can swiftly generate the necessary cash (Suadi *et al.*, 2022). However, selling assets or using savings is not sustainable in the long term. Therefore, fishermen must explore alternative livelihood options and access financial support mechanisms to enhance household economic resilience.

Social adaptation

Social adaptation encompasses empowering local communities and integrating farmers into decision-making processes, which involves local capacity building, community support, and the incorporation of local knowledge. This adaptation arises from fishermen's involvement in cohesive communities where they collaborate, exchange information, and assist one another. Social adaptation in the fisheries sub-sector is presented in Fig. 10.

Social relationships

Social relationships aim to enhance solidarity and harmony among fishing communities. The benefits of social bonds encourage cooperation among fishermen to share resources knowledge, and support each other, especially in difficult times. The enhancement of social cohesion has the potential to bolster the resilience of communities and make a positive impact on the overall well-being of fishing communities. Suadi *et al.* (2022) mention examples of social relations in fishing communities through "gotong royong" activities. Another study emphasizes social network utilization as social adaptation in the community (Mulyasari *et al.*, 2018, 2021).

Fisherman groups

The fishermen's group serves as a forum for exchanging information about weather conditions, fishing locations, new technologies, or fishing regulations. It assists members of the group in expanding their knowledge and enhancing their efficiency in carrying out fishing tasks. Fishing groups engage in a range of activities, such as sharing information on climate change (Mulyasari *et al.*, 2018, 2021) and fish skills training (Hafsaridewi *et al.*, 2021).

Determinant factors of CCAM

Farmers can select and implement one or more adaptation strategies based on their farming characteristics and financial capabilities (Connor *et al.*, 2021; Imelda *et al.*, 2023). Based on document reviews, at least three main socioeconomic factors influence CCAM: individual characteristics, access to resources, and social institutions. Individual characteristics such as gender, age, education, experience, social status, and culture can affect adaptive capacity. In the context of pepper farming, it is observed that female farmers tend to embrace climate change strategies to a greater extent compared to their male counterparts (Irawan, 2021). Age, education, and experience affect farmers' ability to access climate change information and increase opportunities to adopt CCAM (Rahayu *et al.*, 2022; Setiawan *et al.*, 2022; Anshori *et al.*, 2023). Access to capital, land, labor, and infrastructure facilitates farmers adopting adaptation practices. Farmers who have restricted access to capital may face challenges in acquiring necessary production inputs or implementing certain technologies, which in turn hinders the implementation of CCAM strategies. Having larger households allows for family members to contribute to adaptation efforts and reduce production expenses (Reed *et al.*, 2017). Involvement in institutions and social networks such as government agencies, none governmental organizations (NGOs), and farmer groups also positively impacts farmers' adaptation behavior (Hasibuan *et al.*, 2023). Efforts can be undertaken to enhance the adaptive capacity of farmers through the dissemination of information and technology related to climate change (Sekaranom *et al.*, 2021). Through farmer institutions, farmers can access the information, resources, and support needed to enhance their capacity and adopt CCAM practices (Suminah and Anantanyu, 2023). The active participation of extension workers has a beneficial effect on the implementation of CCAM practices as it raises awareness about climate change and encourages individuals to adopt suitable strategies (Irawan and Syakir, 2019; Massagony *et al.*, 2023). Microfinance support facilitates adoption by providing financial resources (Chirambo, 2017).

Evaluation of CCAM in the agricultural sector

CCAM in the agricultural sector can lead to negative trade-offs; for instance, transitioning from monoculture to multiculture systems may reduce productivity until farmers optimize management for the new crops. Replanting may temporarily decrease production and income until the plants yield again (Novra and Suparjo, 2020). Despite the long-term benefits of agricultural technology in terms of productivity, efficiency, and profitability, smallholder farmers with limited financial resources face the challenge of significant upfront investment and maintenance costs. Positive benefits of CCAM were reported in previous studies. Rahman *et al.* (2023) found that CCAM strategies increased fishermen's happiness and life satisfaction, indicating improved well-being. Connor *et al.* (2021) highlighted the success of CCAM in enhancing social capital, human capital, and poverty alleviation among farmers. It was also observed that the implementation of two adaptation practices resulted in greater advantages compared to the implementation of only one. The results indicate that although there could be initial trade-offs between CCAM and agricultural productivity, effective strategies can result in lasting advantages such as enhanced well-being and resilience within farming communities. Therefore, policymakers and stakeholders should prioritize comprehensive adaptation strategies that address environmental sustainability and farmer well-being to achieve sustainable agricultural development.

CONCLUSION

This study assesses the efforts of smallholder farmers in Indonesia to adopt CCAM strategies in the crop farming and fisheries sub-sectors. Literature reviews focusing on CCAM in the Indonesian agricultural sector are still lacking or, at best, limited. The objective of this research is to address this deficiency by pinpointing CCAM approaches within every agricultural division and classifying them into ecological, economic, and social adjustments. The study's findings are based on a review of previous studies on climate change impacts, adaptation and mitigation strategies, and the agricultural sector in Indonesia. A search on the Scopus database and PRISMA analysis yielded 52 studies on CCAM from 2010-2023 in Indonesia. There are four main findings in this literature study. First, most studies on CCAM in Indonesia were focused on crop farming (60%), followed by the fisheries sub-sector (23%) and general agriculture (17%). Geographically, most studies were concentrated in Java (46%), with some representation from Sumatra (21%), Sulawesi (17%), and Nusa Tenggara (2%). Second, the CCAM strategies were classified into three categories: ecological, economic, and social. Striking a balance between environmental approaches, economic objectives, and social welfare is advantageous in attaining sustainable agriculture. The comprehensive approach insures that all three elements are taken into account collectively when making agricultural decisions. Ecological adaptation, such as technology adoption and farming management practices, was commonly reported in crops and fisheries. Economic adjustment encompassed diversifying livelihoods and selling assets, whereas social adjustment entailed utilizing indigenous knowledge and collaborating with farmer associations. Third, the study explores the socioeconomic factors as determinants of CCAM, including individual characteristics, resource access, and institutional involvement. Farmers' adaptive capacity is influenced by individual characteristics such as gender, education, and access to resources. Fourth, CCAM strategies can have short-term trade-offs, such as reduced productivity during transitions or initial investment burdens for smallholder farmers. Conversely, there are enduring advantages, such as enhanced welfare and fortitude. Comprehensive CCAM strategies addressing environmental sustainability and farmer welfare are crucial for sustainable agriculture. The study underscores the significance of expanding research efforts, particularly in regions with limited representation, like Kalimantan, Nusa Tenggara, and eastern Indonesia. There's a call for more studies focusing on other agricultural sub-sectors, such as plantation, fisheries, and livestock, to provide a more comprehensive understanding of CCAM strategies across different sectors. The significance of this study lies in its potential to offer valuable insights that can inform policymaking and improve support mechanisms for smallholder farmers confronting the challenges of climate change. By identifying efficient CCAM strategies and addressing gaps in knowledge, policymakers can formulate precise approaches to mitigate the effects of climate change on agricultural communities. This will ultimately promote resilience and sustainable development in the face of environmental challenges. Policy recommendations from the study include: 1) developing policies to support CCAM through ecological, economic, and social approaches, including support for environmentally friendly technologies, sustainable farming practices, livelihood diversification, and strengthening farmer groups to utilize local knowledge, 2) the importance of investing in infrastructure development such as irrigation systems and market facilities to enhance farmers' access to resources, and 3) strengthening extension and capacity-building action to provide knowledge and skills to farmers, as well as promoting collaboration among diverse stakeholders such as government, research institutions, NGOs, and farmer organizations to develop holistic CCAM strategies.

AUTHOR CONTRIBUTIONS

Imelda was responsible for searching and selecting relevant literature, summarizing, writing, and revising the manuscript. R. Hidayat was responsible for conceptualizing the draft, writing, and revising the manuscript.

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CONFLICT OF INTEREST

The authors declare that there are no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, were observed by the authors.

OPEN ACCESS

PUBLISHER'S NOTE

ABBREVIATIONS

ABBREVIATIONS	DEFINITION
%	Percent
CCAM	Climate change adaptation and mitigation
El Nino	A characterized by unusually warm ocean temperatures in the central and eastern tropical Pacific Ocean
Fig.	Figure
GDP	Gross domestic product
GT	Gross tonnage
KUR	"Kredit Usaha Rakyat"

La Nina	A characterized by unusually cold ocean temperatures in the central and eastern tropical Pacific Ocean
n	Number of documents
NGOs	Non-governmental organizations
PRISMA	Preferred reporting items for systematic reviews and meta-analyses

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