

Resilience OF Red Chili Farming Amid Climate Variability: Risk Analysis AND Mitigation Strategies

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Abstract

Climate change and climate variability pose significant challenges to agricultural sustainability, particularly for horticultural crops such as red chili, which are highly sensitive to fluctuations in temperature, rainfall, and wind. This study aims to analyze the impact of climate variability and climate change on red chili production in West Java, Indonesia, and to develop adaptation and mitigation strategies to strengthen agricultural resilience. Using historical climate data from 2014 to 2024—including temperature, rainfall, humidity, and wind speed—alongside production data (land area, yield, and related factors), the study applies mixed methods combining statistical analysis and farmer surveys.

The results indicate an average 20% decline in red chili production between 2019 and 2023, largely due to unstable rainfall patterns, temperature extremes, and shifts in wind speed. Farmers were found to be highly vulnerable to these climatic shocks, with limited access to adaptive technologies and resources. To address these challenges, the study proposes a set of strategies: the adoption of adaptive farming technologies such as drip irrigation and resilient varieties, crop diversification, continuous farmer capacity building, improved climate information systems, and stronger policy support.

The findings highlight the urgent need for integrated adaptation and mitigation approaches that combine technological, institutional, and policy measures. Recommendations include the development of more advanced agricultural technologies, wider market access for alternative crops, breeding of adaptive local varieties, and integration of climate information systems with mobile applications. A comprehensive approach encompassing technology, diversification, training, and supportive policies is expected to enhance the resilience of red chili farming and ensure sustainable production in the future.

Keywords: Climate_variability, Climate_change, Red_chili, Adaptation_strategies, Agricultural_resilience

INTRODUCTION

Climate change has become one of the most pressing global issues, with widespread impacts across various aspects of life, including agriculture, which plays a vital role in the global economy and food security. Agriculture, particularly vegetable crops, is highly vulnerable to climate change, where temperature fluctuations and irregular rainfall patterns can disrupt crop growth and yields. As one of the most important commodities in the global food system, vegetables, including red chili, face serious threats from the drastic impacts of climate change (Rusmayadi et al., 2018).

The increase in global temperature as a result of climate change not only reduces the production of desired crops but also stimulates weed growth and pest outbreaks, further worsening production conditions. In addition, changing rainfall patterns increase the risks of short-term crop loss and cause long-term damage, ultimately threatening food security in many developing countries that rely heavily on agriculture for their livelihoods (Hatfield et al., 2015). Indonesia, as an agrarian country severely affected by climate change, experiences these impacts acutely, especially in the horticultural sector such as red chili cultivation.

In this context, farmers in Indonesia, particularly in red chili-producing regions such as West Java, face growing challenges. Unstable climatic conditions have led to significant declines in red chili production in the region. Temperature fluctuations, irregular rainfall, and varying wind speeds affect the growth requirements of red chili, which ideally requires a temperature of 24–27 °C, humidity of 70–80%, rainfall of 50–105 mm per month, and stable wind speed for optimal pollination (Ridwan et al., 2020). This decline in production directly impacts farmers' incomes and the supply of red chili in both domestic and international

markets, which in turn affects price stability and the sustainability of the agricultural economy (Catriana et al., 2023).

Unstable climatic conditions, such as extreme temperature increases, irregular rainfall, and shifting weather patterns, have placed an even greater burden on smallholder and subsistence farmers. In developing countries like Indonesia, where livelihoods heavily depend on agriculture, farmers are particularly vulnerable to climate fluctuations. Agricultural production, especially for crops such as red chili, is highly affected by unpredictable climatic conditions, resulting in declining yields and reduced income.

Smallholder farmers often lack sufficient resources to invest in climate adaptation technologies, such as more efficient irrigation systems, climate-resilient crop varieties, or environmentally friendly farming practices. Socio-economic factors, including limited access to finance, technology, and information, further constrain their adaptive capacity. In addition, inadequate political support and policies to assist farmers in addressing climate change exacerbate this situation.

As a result, smallholder farmers face a higher risk of crop failure, which can lead to reduced income and heightened economic vulnerability. In Indonesia, where agriculture plays a crucial role in the rural economy, farmers' inability to adapt to climate change may deepen social and regional inequalities, worsen poverty, and threaten national food security (Kreft et al., 2017).

Although several mitigation measures have been introduced, such as limiting irrigation water use and reducing chemical inputs in agriculture, the response to climate change in the agricultural sector remains insufficient. These efforts, while important, are often inadequate to address the challenges faced by farmers. Restricting irrigation use aims to reduce water consumption and prevent waste, but it is often insufficient to cope with severe water shortages caused by climate change. Similarly, reducing chemical inputs can lessen environmental impacts but does not necessarily strengthen crop resilience under changing climatic conditions.

The decline in red chili production not only affects farmers' welfare but also has broader implications for sustainable economic development. Red chili crop failures can lead to significant economic losses for farmers and increase social burdens due to unstable supply and fluctuating market prices (Deressa et al., 2011). Therefore, in-depth studies on the impacts of climate change on red chili production are critical to identifying effective solutions and developing more robust adaptation and mitigation strategies (Nelson et al., 2009). Enhancing agricultural resilience in the face of climate change requires more progressive and innovative measures, including the adoption of climate-smart technologies, farmer capacity building, and the integration of supportive policies that strengthen food security and sustainable development (Lobell et al., 2022). This study is expected to provide significant contributions to understanding the impacts of climate change on red chili production as a basis for practical solutions to minimize crop failure risks and their economic and developmental consequences in Indonesia.

LITERATURE REVIEW

1. Climate Variability and Climate Change in the Indonesian Context

Climate variability refers to fluctuations in climatic conditions from year to year or between seasons, while climate change refers to long-term shifts in climate patterns resulting from the increasing concentration of greenhouse gases in the atmosphere. Globally, the average surface temperature has already risen by more than 1.1°C compared to the pre-industrial era, and projections indicate that this trend will continue through the end of the 21st century (IPCC, 2021). This phenomenon not only triggers changes in rainfall patterns and seasons but also increases the frequency of extreme climate events such as droughts, floods, and heatwaves.

Indonesia, as a tropical archipelago, has unique climatic characteristics influenced by global circulation systems such as the El Niño Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), and the Asian-Australian monsoon. Data from the Meteorology, Climatology, and Geophysics Agency (BMKG, 2025) show that the average air temperature anomaly in Indonesia reached +0.8 °C in 2024, reflecting a consistent warming trend. Furthermore, BMKG (2024) also recorded an increase in the number of extreme rainfall days (>20 mm per day) in various regions, as well as shifts in the onset and end of the rainy and dry seasons. These changes complicate the planning of planting seasons, especially for horticultural commodities that are highly sensitive to weather fluctuations.

The shift in seasons has become increasingly evident in 2025, when BMKG announced that the dry season began later than initially predicted (BMKG, 2025). In previous years, the strong El Niño of 2023 caused reduced rainfall and widespread crop failures in chili-producing regions (As'ari, 2023). These phenomena highlight that both seasonal climate variability and long-term climate change have tangible impacts on Indonesia's agricultural sector.

The implications of these climatic dynamics are substantial for red chili production. As a commodity with high economic and social value, red chili often serves as an indicator of food stability and inflation in Indonesia. The uncertainty of planting seasons, driven by shifts in rainfall patterns, makes it difficult for farmers to determine optimal planting times, thereby increasing the risks of crop failure and price fluctuations. Understanding patterns of climate variability and climate change in Indonesia is therefore a critical first step in designing effective adaptation and mitigation strategies for the sustainability of the horticultural subsector.

2. Mechanisms of Climate Impacts on Red Chili Production

Red chili (*Capsicum annum*) is a horticultural crop highly sensitive to environmental conditions. Its growth and productivity are influenced by a combination of climatic factors such as temperature, rainfall, humidity, and light intensity. According to Agromet IPB (2017), even small changes in air temperature can significantly affect the physiological processes of the plant, including flowering, pollination, and fruit formation. The optimal temperature range for chili growth is between 20–30 °C, while temperatures above 32 °C often cause pollination failure and reduce fruit quality.

Rainfall also plays a key role in determining production success. During high-rainfall seasons, increased humidity creates favorable conditions for pathogens causing diseases such as anthracnose and bacterial wilt. Naura (2018) notes that in wet seasons, disease intensity in chili plants can double compared to normal seasons, leading to yield losses of 20–40%. Conversely, prolonged dry periods associated with El Niño events often result in water stress, which hampers both vegetative and generative growth. As a result, fruits tend to be smaller, thinner-skinned, and less resistant to storage.

In addition to temperature and rainfall, strong winds are another ecological constraint in chili cultivation. Wind can damage flowers and cause fruit drop, which, if recurrent, significantly reduces harvest volumes. Meanwhile, unpredictable seasonal changes complicate farmers' ability to establish accurate planting calendars, often resulting in mismatches between crop growth phases and optimal climatic conditions.

Thus, the mechanisms of climate impacts on red chili can be summarized into three main aspects: (1) physiological stress caused by temperature and drought; (2) increased disease risk due to high humidity; and (3) physical damage caused by extreme wind and rainfall. The combination of these factors makes red chili an extremely climate-sensitive crop, requiring specific, science-based adaptation strategies.

3. Adaptation and Mitigation Strategies for Sustainable Development

In addressing the challenges of climate variability and climate change, the agricultural sector needs to develop comprehensive adaptation and mitigation strategies. One widely adopted approach is Climate-Smart Agriculture (CSA), which emphasizes three primary objectives: increasing agricultural productivity, strengthening resilience to climate change, and reducing greenhouse gas emissions (World Bank, 2021).

At the technical level, adaptation in chili cultivation can be achieved through the implementation of water-saving technologies such as drip irrigation and rainwater harvesting. Haryati (2012) emphasized that rainwater harvesting using reservoirs and small dams can provide additional water resources during the dry season. Similarly, the use of plastic or organic mulch has proven effective in maintaining soil moisture, suppressing weed growth, and stabilizing soil temperature (Kartika et al., 2019). These innovations not only improve crop yields but also reduce dependence on costly external inputs.

Furthermore, the selection of disease-resistant superior varieties is an important step in reducing risks associated with high humidity. The Indonesian Vegetable Research Institute (Balitsa) released the *Canci Agrihorti* chili variety in 2022–2023, which is resistant to anthracnose disease, making it suitable for cultivation during the rainy season. This varietal innovation demonstrates that technology-based adaptation can reduce production losses while supporting food security.

From a mitigation perspective, the adoption of environmentally friendly agricultural practices—such as the use of organic fertilizers, incorporation of organic matter into soils, and agroforestry integration—can reduce

carbon emissions. FAO (2021) emphasizes that mitigation practices combined with adaptation strategies can provide co-benefits, not only reducing greenhouse gas emissions but also enhancing productivity, soil quality, and farmers' livelihoods.

At the institutional level, the success of adaptation and mitigation is also determined by the availability of climate information services, access to financing, and the strengthening of farmer organizations. Climate information provided by BMKG can assist farmers in determining more accurate planting schedules. Meanwhile, access to agricultural insurance and climate-friendly credit can help reduce the economic risks associated with crop failure.

Through the combination of technical, institutional, and policy approaches, adaptation and mitigation strategies in the red chili sector are not only focused on increasing production but are also aligned with the goals of sustainable development, particularly SDG-2 (Zero Hunger) and SDG-13 (Climate Action).

METHODOLOGY

1. Research Location

This study was conducted in West Java Province, one of the main centers of red chili production in Indonesia. The selection of West Java as the research site was based on its significant contribution to national chili production and its vulnerability to climate variability and change. Agroecologically, West Java exhibits diverse environmental conditions, ranging from lowland areas with relatively high temperatures to highland regions with cooler climates. This variability makes the province highly representative for analyzing the impact of climate variability on red chili production..

Administratively, the research was focused on several key red chili-producing districts, namely Bandung, Garut, and Cianjur. Bandung was selected because it has a relatively large cultivation area for red chili and serves as one of the main suppliers to both regional and national markets. Garut is known as a horticultural hub with high red chili productivity, but it often faces climate-related challenges such as extreme rainfall that triggers floods and landslides. Meanwhile, Cianjur was chosen due to its strategic location and its crucial role in distributing chili to the Greater Jakarta (Jabodetabek) region. In addition to productivity considerations, these areas are also frequently affected by climate fluctuations that cause crop failures and reduced yields, making them highly relevant to the research objectives, which focus on the impacts of climate on agricultural.

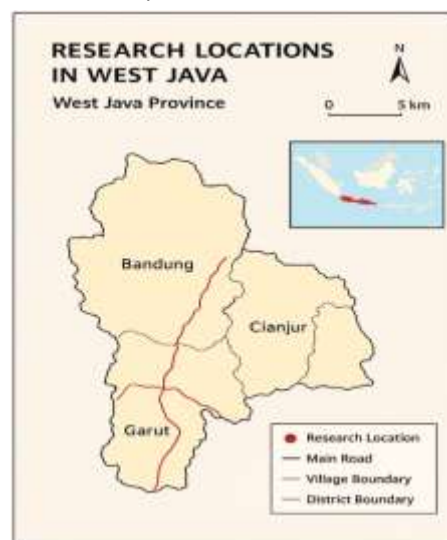


Figure 2. Research Locations of Red Chili Production Centers in West Java, Indonesia

The map illustrates the main study areas consisting of Bandung, Garut, and Cianjur districts in West Java Province. These districts were selected due to their significant contributions to national red chili production and their high vulnerability to climate variability and change. Bandung represents a major production hub with extensive cultivation areas. Garut, while recognized for its high horticultural productivity, often experiences extreme rainfall leading to floods and landslides. Cianjur, strategically located, plays a vital role in the distribution of red chili to the Greater Jakarta (Jabodetabek) region. The spatial distribution of these

districts reflects both the economic importance and climatic challenges faced by red chili farmers in West Java.

2. Data Collection Techniques

Data collection was carried out using a mixed-methods approach (quantitative and qualitative) to obtain more comprehensive research results. The data used consisted of both secondary and primary data.

a. Secondary Data

Secondary data were obtained from various relevant institutions, such as the Meteorology, Climatology, and Geophysics Agency (BMKG), the West Java Provincial Agriculture Office, and the Central Bureau of Statistics (BPS). The climate data collected included air temperature, rainfall, humidity, and wind speed over the past five years. These data were used to analyze climate variability trends in the research area. In addition, red chili production data—including cultivated area, harvested area, productivity, and yield per hectare—were collected from annual agricultural statistical reports. Data on pest and disease outbreaks were also compiled as supporting factors in analyzing climate-related losses.

b. Primary Data

Primary data were obtained through in-depth interviews and the distribution of structured questionnaires to red chili farmers in the study areas. The interviews explored farmers' perceptions of climate change, the impacts they experienced, and the adaptation strategies they had applied locally. The questionnaires were used to collect quantitative data on the frequency of crop failures, the magnitude of economic losses due to climate change, additional adaptation costs (such as the use of supplementary irrigation or pesticides), and the level of adoption of adaptive agricultural technologies.

This data collection method was conducted using triangulation, combining both secondary and primary data to enhance the validity of the research findings. Thus, the data obtained not only described climate conditions and chili production statistically but also reflected farmers' real experiences in coping with the challenges of climate change.

3. Data Analysis

Data analysis was carried out in stages using both quantitative and qualitative approaches. The analytical steps were designed to provide a comprehensive understanding of the relationship between climate variability and red chili production, while also generating appropriate recommendations for adaptation and mitigation strategies. In addition, the analysis aimed to examine the impacts of climate change on red chili production in West Java by utilizing historical climate data from the past five years. Each stage of the analysis is illustrated in the following figure:

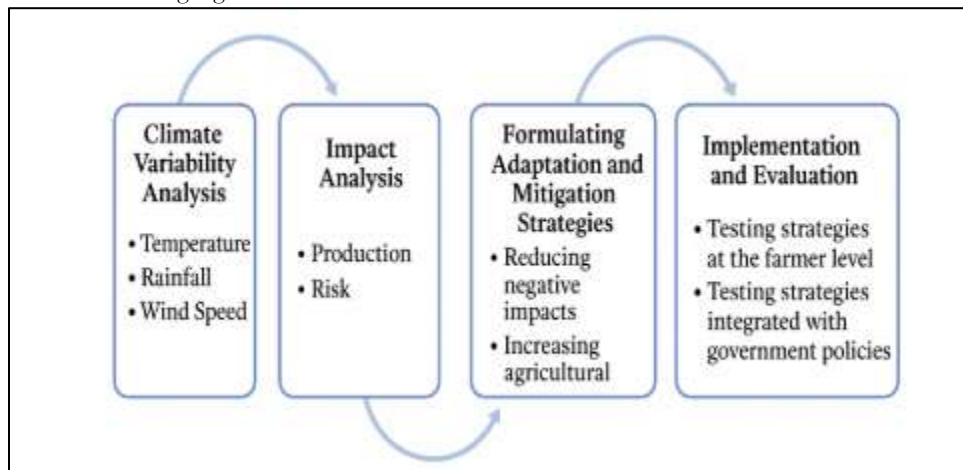


Figure 3: Stages of Research Activity Implementation

a. Historical Data

The initial stage of the analysis was carried out using descriptive statistics to identify patterns and trends in climate data and red chili production over the past five years. This analysis aims to observe the general tendency of changes in climate parameters, such as the increase in average temperature, the intensity of extreme rainfall, and the frequency of anomalous climate events such as drought.

b. Climate Variability Analysis

The collected climate data were analyzed using climate variability indices to measure the magnitude of year-to-year changes in climate parameters. This analysis is crucial to determine the extent to which climate fluctuations affect the growth cycle of red chili. Through this approach, it is possible to identify critical periods when climate change has the most significant impact on production.

c. Impact Analysis on Production

The relationship between climate variability and red chili production was analyzed using a multiple linear regression model. This model allows researchers to determine the extent of the influence of each climate variable (temperature, rainfall, humidity, and wind speed) on red chili productivity. Thus, it can be mapped which climate variables are most dominant in influencing yields and how much they contribute to the decline in productivity.

d. Formulation of Adaptation and Mitigation Strategies

To assess the potential losses faced by farmers, a risk assessment method was used. This analysis calculates the probability of extreme climate events and their impact on farmers' productivity and income. Risks are calculated by considering land vulnerability, damage intensity, and farmers' adaptive capacity. The results of this risk analysis provide an overview of the severity of climate change threats to red chili production.

e. Implementation and Evaluation

The final stage is to formulate adaptation and mitigation strategies using the SWOT analysis approach (Strengths, Weaknesses, Opportunities, Threats). This analysis aims to identify potential strengths and opportunities that can be utilized, as well as weaknesses and threats that need to be addressed. The strategies produced are not only focused at the farmer level but also directed at supporting local government policies to reduce the negative impacts of climate change and enhance food security.

Through these stages of analysis, the research is expected to provide a comprehensive understanding of the interaction between climate and red chili production, as well as generate evidence-based recommendations for adaptation and mitigation strategies.

RESULTS AND DISCUSSION

a. The Impact of Climate Variability on Red Chili Production

Fluctuations in temperature, irregular rainfall, and varying wind speeds have direct impacts on the quality and quantity of harvests. Temperatures that frequently exceed the optimal range of 24–27°C affect the photosynthesis and pollination processes of chili plants, resulting in decreased productivity. Unstable rainfall further complicates this condition, with periods of drought and excessive rain damaging crops and disrupting their growth cycles (Wheeler et al., 2013). In addition, fluctuating wind speeds influence pollination processes and worsen farmland conditions.

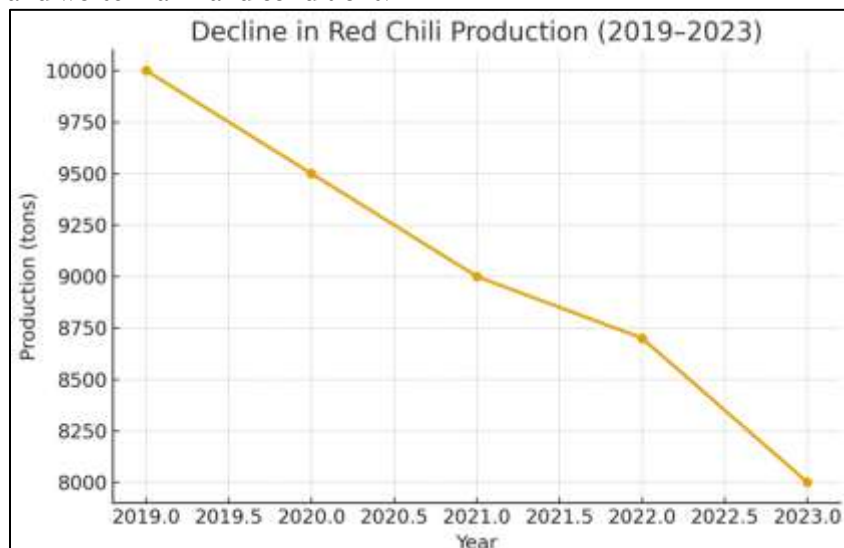


Figure 3. Decline in red chili production between 2019 and 2023

The results indicate an average 20% decline in red chili production between 2019 and 2023. Based on data from the Central Statistics Agency (BPS), red chili production decreased from approximately 10,000 tons in 2019 to 8,000 tons in 2023. The decline was most pronounced during the El Niño period in 2020–2022, when rainfall variability disrupted planting schedules and reduced harvest yields. This finding is consistent with previous studies that link climate anomalies to production losses in horticultural commodities (Marina et al., 2025; Sukmawati et al., 2024). This decline is directly linked to the increase in average temperature, which exceeded the optimal threshold for chili growth, with averages reaching 28–30°C in recent years. Inconsistent rainfall has also been a critical factor, fluctuating between 60–150 mm per month, affecting plant health and causing significant damage to yields (Vermeulen et al., 2012).

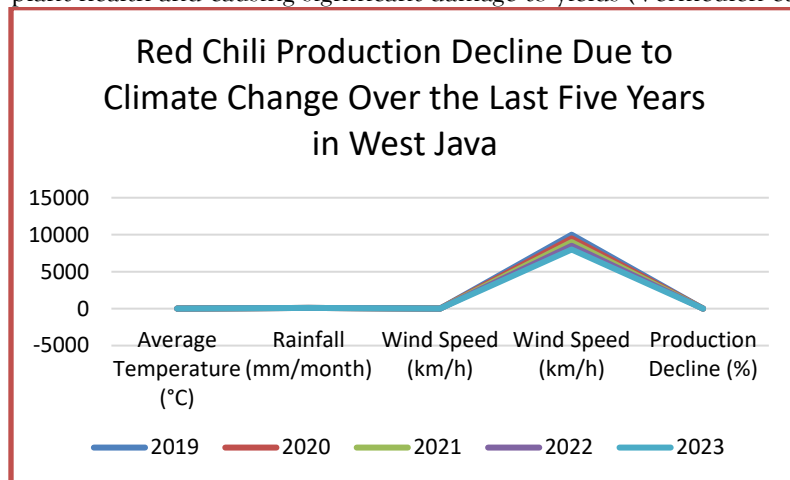


Figure 4. Decline in Red Chili Production Due to Climate Change Over the Last Five Years in West Java

Unstable wind speeds add further complexity to this problem. For example, in 2021, wind speeds varied between 12–25 km/h, exceeding the optimal range of 10–20 km/h required for effective pollination (Challinor et al., 2014). This worsens the situation for red chili farmers who rely on stable climatic conditions for optimal harvests. As a result of climate change, farmers face an increased risk of crop failure, with several production centers reporting yield losses.

This decline in production not only adds to the economic burden on farmers but also disrupts the supply of red chili in local markets. The rise in chili prices due to reduced production also affects consumers and the trade sector, creating market instability. Furthermore, this production decline has broader implications, such as unstable red chili supplies in local markets and price increases that impact consumers and the trade sector. In addition, it exacerbates the economic burden on smallholder farmers who have limited adaptive capacity to climate variability.

b. Risk and Vulnerability Identification of Farmers

Farmers in West Java, particularly smallholders, show high vulnerability to climate fluctuations that affect their income stability. Based on data from five districts—Sukabumi, Site 5, Site 1, Site 4, and Site 2—a clear picture of the impacts of climate change over the last five years (2019–2023) was obtained.

Climate fluctuations and extreme weather risks in Sukabumi and Site 1 have caused significant declines in red chili production due to climate change. Extreme weather, including floods and droughts, has been a major factor affecting yields. In Site 5, farmers also faced reduced yields due to unstable temperature and rainfall patterns. In Site 4, farmers reported an increase in pest and disease outbreaks triggered by extreme changes in temperature and humidity. These conditions have worsened their vulnerability to crop failure and income instability (Lesk et al., 2016).

In Site 2 and Sukabumi, as major production centers, changes in rainfall intensity have affected soil quality. Waterlogged soils due to heavy rainfall reduced soil fertility and disrupted red chili growth. On the other hand, prolonged droughts have also decreased soil quality and reduced crop productivity. In Site 4, changes in soil quality further impacted red chili productivity, weakening plants' resilience to environmental stress and increasing the risk of farmer losses.

In several production centers, smallholder farmers lack adequate access to adaptation technologies and climate change information. In Site 5 and Site 1, limited knowledge of adaptation techniques reduced farmers' ability to cope with climate change impacts. Socio-economic factors such as low education levels and limited access to financial resources make farmers more vulnerable to climate fluctuations. Similarly, in Sukabumi and Site 2, farmers with lower education levels tended to have less understanding of agricultural practices that could mitigate climate change impacts.

Changes in soil conditions have further worsened the situation (Reynolds et al., 2007). In Sukabumi, around 40% of farmland has experienced soil degradation due to high rainfall intensity. Meanwhile, in Site 2, prolonged drought in 2021 reduced soil fertility, negatively affecting red chili growth. Farmers in these areas also face significant socio-economic vulnerabilities, including limited access to climate adaptation technologies and low education levels. Previous studies showed that around 60% of farmers in Site 5 and Site 1 lacked adequate access to technologies that could help them adapt to climate change.

Mitigation efforts, such as the use of adaptation techniques and adjustments in planting schedules, have been initiated by some farmers in Site 2 and Site 1. However, the effectiveness of these techniques remains limited, and many farmers have not been able to adopt them properly. Meanwhile, the price of red chili in local markets has continued to rise due to declining production, further worsening the economic conditions of smallholder farmers. Between 2019 and 2023, red chili prices increased by 40%, adding social and economic burdens for farmers already struggling with yield reductions. Although local governments have attempted to provide training and support, responses to climate change in the agricultural sector remain far from optimal.

c. Evaluation of Climate Change Impacts on Red Chili Production in Major Production Centers of West Java

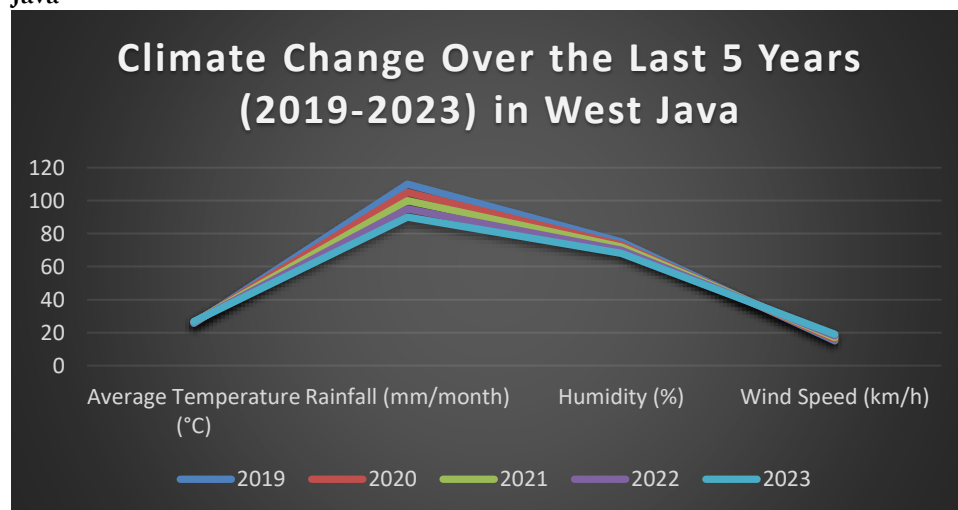


Figure 5. Climate Change Over the Last Five Years (2019–2023) in West Java

The evaluation of climate change impacts on red chili production in major production centers of West Java—namely Site 1, Site 5, Site 3, Site 2, and Site 4—shows a significant decline in production due to increasingly irregular climate variability. Based on historical climate data from 2014 to 2024, trends of rising average temperatures, unstable rainfall, and shifting wind patterns have been identified. These climatic conditions directly affect red chili growth, which ideally requires temperatures of 24–27°C, humidity levels of 70–80%, stable rainfall of 50–105 mm per month, and wind speeds of 10–20 km/h for optimal pollination.

Site 3 recorded the largest decline, with production falling by 30% due to rising temperatures and uneven rainfall. Site 1 and Site 5 also experienced yield reductions of 20–25% as a result of higher temperatures and humidity that influenced plant growth and pest outbreaks. In Site 2 and Site 4, although the decline was more moderate, farmers still faced climate uncertainty that disrupted planting and harvesting schedules.

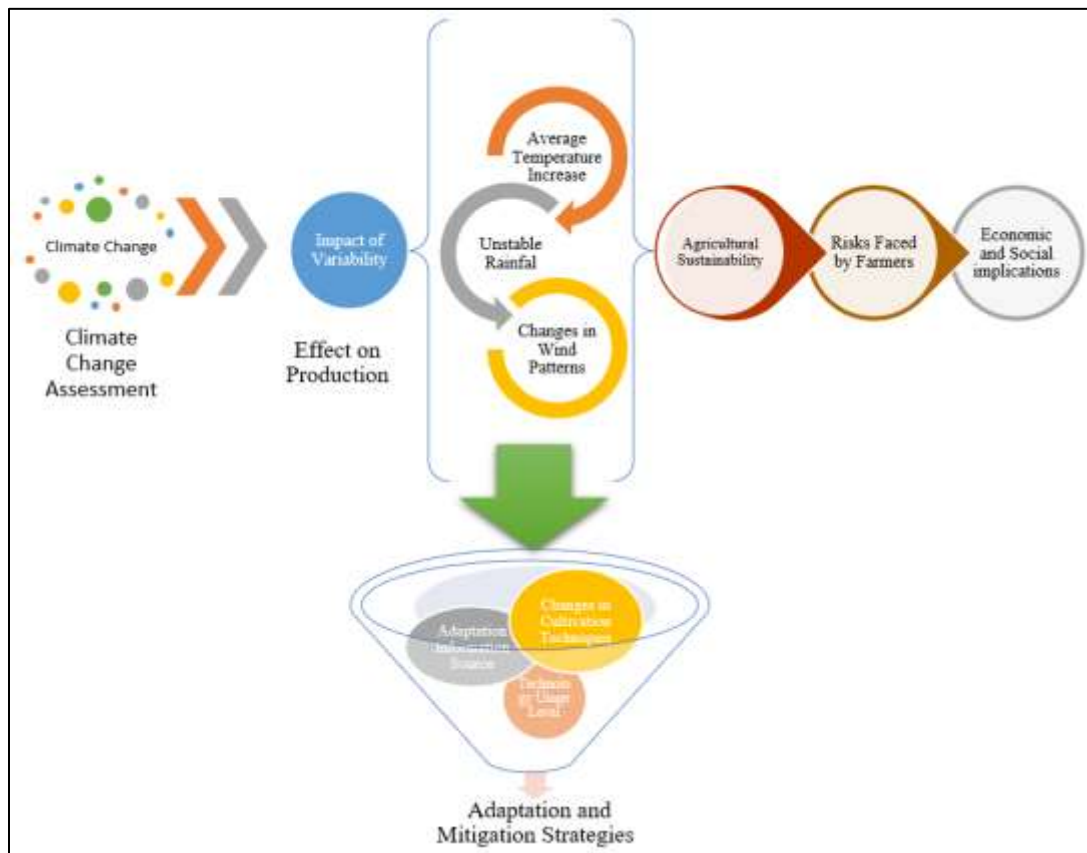


Figure 6. Impacts of Climate Variability and Climate Change on Chili Production Centers in West Java

Climate change increases risks for farmers, especially smallholders and subsistence farmers who have limited adaptive capacity. Fluctuations in temperature and rainfall result in significant economic losses for farmers due to reduced yields and increased production costs for pest control. In addition, the instability of red chili supply in the market leads to price fluctuations that disadvantage farmers. They often lack access to adequate technologies or adaptation strategies, such as modern irrigation systems or climate-resilient seed varieties, which could help reduce the negative impacts of climate change (Marina et al., 2024).

The decline in red chili production affects not only farmers' livelihoods but also the stability of supply in local and national markets. This supply instability causes chili prices to fluctuate upward, creating economic pressure on consumers and leading to market instability (Marina et al., 2024). For farmers, these economic losses are compounded by social burdens such as increased debt and dependence on government assistance. In areas such as Site 4 and Site 3, where dependence on agriculture is high, these impacts are more pronounced, increasing vulnerability to poverty.

d. Adaptation and Mitigation Strategies for the Impacts of Climate Change on Red Chili Production in West Java

Various adaptation and mitigation strategies have been developed to enhance the resilience of red chili farming, based on the analysis of climate change impacts and local conditions in each district, as presented in Table 1 :

Table 1. Adaptation and Mitigation Strategies of Chili Farmers in Major Production Sites of West Java

Location	Mitigation Effort	Description of Effort	Success Rate	Improvement Recommendations
Site 1	Crop Diversification	Farmers plant alternative crops that are more resilient to extreme weather to reduce the risk of crop	70%	a) Expand diversification with crops that have shorter harvest cycles to support income sustainability. b) Provide wider market access for non-chili products.

Location	Mitigation Effort	Description of Effort	Success Rate	Improvement Recommendations
		failure due to unstable climatic conditions.		
Site 2	Implementation of Drip Irrigation	A water-efficient irrigation system to maintain optimal soil moisture, especially during the dry season and rainfall fluctuations.	75%	a) Develop sensor-based automated irrigation technology to improve water-use efficiency. b) Provide government subsidies to expand the use of drip irrigation among smallholder farmers.
Site 3	Use of Climate-Resilient Chili Varieties	Utilization of red chili seeds that are more resistant to high temperatures and extreme weather to maintain productivity under climate change.	65%	a) Develop local varieties that are more adaptive to microclimatic conditions. b) Conduct continuous research to improve chili resistance against pests and diseases triggered by climate change.
Site 4	Farmer Capacity Building through Training	Training for farmers on adaptation techniques, climate risk management, and the use of organic fertilizers to enhance sustainable productivity.	80%	a) Develop continuous training programs focusing on precision agriculture technologies. b) Provide incentives to farmers who successfully apply training techniques to encourage wider adoption.
Site 5	Strengthening Climate Information and Early Warning Systems	Implementation of technology-based early warning systems to help farmers prepare for extreme weather and adjust planting schedules.	85%	a) Integrate climate information systems with mobile applications that are more accessible to farmers. b) Provide digital extension services for farmers to respond to climate information in real-time.

One important recommendation is the integration of climate information systems with mobile applications, such as weather forecasting apps (for short-term rainfall prediction), farmer advisory tools (for planting and fertilization schedules), and decision-support systems (for risk analysis and crop management). The combination of these tools can provide farmers with timely and practical information to minimize risks associated with climate variability. Evidence from pilot projects in Indonesia (Harti et al., 2024) and India (Singh et al., 2022) has shown that mobile-based climate advisory systems significantly improve farmer decision-making and reduce crop losses.

Farmer capacity building through training is also a priority, as in Site 4. This program provides education on how to manage climate change risks, including the use of organic fertilizers and environmentally friendly pest management techniques (Hansen et al., 2011). On the other hand, strengthening climate infrastructure and information systems has been proposed as a long-term solution. In Site 5, the development of information technology-based early warning systems helps farmers prepare for extreme weather, enabling them to adjust planting schedules based on accurate weather forecasts. Partnerships between local governments, research institutions, and the private sector in Site 3 have facilitated the implementation of technological solutions and the distribution of resources. Local governments have also allocated budgets for climate change impact mitigation programs and provided both technical and financial assistance to farmers ((Marina et al., 2025).

CONCLUSION

Climate variability, such as temperature fluctuations, unstable rainfall, and varying wind speeds, has a direct impact on the quality and quantity of red chili production. Temperatures exceeding the optimal range of 24–27°C disrupt photosynthesis and pollination processes, leading to reduced productivity. Unstable rainfall, with alternating droughts and excessive rains, damages crops and interferes with their growth cycles. Fluctuating wind speeds also affect pollination and worsen agricultural land conditions. The decline in red chili production in West Java not only increases the risk of crop failure for farmers but also causes supply instability and price fluctuations in the market, which negatively affect both farmers and consumers.

Farmers in West Java, particularly small-scale farmers, show high vulnerability to climate fluctuations. In Sukabumi Regency and Location 1, extreme weather events such as floods and droughts have led to decreased red chili production. Location 5 experienced yield reductions due to temperature fluctuations and unstable rainfall. Location 4 reported increased pest and disease attacks caused by extreme changes in temperature and humidity. In Sukabumi and Location 2, soil quality declined as a result of heavy rainfall or prolonged drought, reducing soil fertility and crop productivity. Many farmers in these areas lack adequate access to climate change adaptation technology and information, making them less capable of coping with its impacts. Limited access to technology, low knowledge, and socio-economic factors such as low education levels exacerbate their vulnerability to climate variability.

The evaluation of climate change impacts on red chili production in West Java's production centers shows a significant decline. Location 3 experienced the largest reduction, reaching 30%, due to rising temperatures and uneven rainfall. Location 1 and Location 5 suffered declines of 20–25% due to rising temperatures and humidity, which affected crop growth and pest emergence. Location 2 and Location 4, although experiencing more moderate declines, still face climate uncertainties that disrupt planting and harvesting schedules. The instability of red chili supply causes price fluctuations that harm farmers and consumers, adding to the economic and social burden of smallholder farmers.

Various adaptation and mitigation strategies have been developed to strengthen the resilience of red chili farming. In Location 1, crop diversification was practiced by planting alternative crops more resistant to extreme weather. In Location 2, drip irrigation systems were applied to maintain soil moisture. Location 3 adopted red chili varieties resistant to extreme climate conditions, while Location 4 focused on strengthening farmers' capacity through training. In Location 5, information technology-based early warning systems were implemented to help farmers cope with extreme weather. Although these efforts have shown success, there is still room for improvement, such as developing automated irrigation technologies, enhancing local varieties, providing continuous training, and integrating climate information systems with mobile applications. These efforts aim to enhance farmers' adaptive capacity and reduce the negative impacts of climate change on red chili production in West Java.

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