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Coffee Production and Coffee Berry Borer *(Hypothenemus hampei)* Condition in Indonesia Related to Climate Change Effect

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ABSTRCT

Effect of climate change on the agricultural sector has been predicted and studied, including its effects on coffee cultivation. Climate change can directly impact coffee production or indirectly influence it through its effects on coffee pests. In Indonesia, coffee is a critical export commodity. Climate change can have a large effect on many farmers if it is not addressed appropriately. This study summarizes several studies and data on how climate change affects coffee production and the coffee berry borer (CBB; *Hypothenemus hampei*) pest in Indonesia. Adaptation plans that can be employed to mitigate impacts of climate change are also summarized.

Keywords: Climate Change, Coffee Berry Borer, Coffee Production, Indonesia

Introduction

Coffee is a valuable export commodity in Indonesia, which is the number 3 country in the world for coffee export (FAOSTAT 2023). Coffee usually grows at low temperatures, especially in elevated areas. The effect of climate change includes a rise in temperature. For coffee that grows in low temperatures, a temperature rise can make some lands unsuitable for planting coffee (Grüter *et al.*, 2022). Climate change also can change the behavior of pests. In some cases, pests can be more aggressive and multiply faster (Agegnehu *et al.*, 2015; Jaramillo *et al.*, 2010).

The climate change effect on coffee plantations and pests can lead to decreased coffee production and loss of the economy (Koh *et al.*, 2020). To prevent that, we must study how climate change affects coffee production and pest attack so that we can prepare a strategy to mitigate the loss of coffee production and the economy due to climate change. One thing that we can do is to observe and learn from other countries and compare it with what is happening in Indonesia.

In this study, we will explore conditions of coffee cultivation and the coffee berry borer (*Hypothenemus hampei*) pest in Indonesia, the ongoing climate change, and its effects on coffee production and coffee berry borer infestation. With this information, we can anticipate challenges ahead and prepare preventive strategies against adverse impacts of climate change on future coffee farming.

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MATERIALS AND METHODS

This research conducted a literature review using local and international reputable journals and secondary data available from institutions and governments to investigate effects of climate change on coffee production and coffee berry borer (*Hypothenemus hampei*) in Indonesia. This research focused on investigating the impact of climate change on coffee production and coffee berry borer (CBB) in Indonesia and answering how climate change affected coffee production and CBB attacks in Indonesia, what actions were taken to mitigate effects of climate change on coffee production and CBB attack, and what action might be applied to mitigate these impacts.

Climate Patterns Data

Climate data included average temperature and temperature anomalies from 2002 to 2021 and rainfall shifts in Indonesia compared between periods of 1971-1990 and 1991-2010. They were obtained from the Meteorology Climatology and Geophysics Agency. The average rainfall was the annual average rainfall data taken from 91 climate observation stations in Indonesia, while the annual air temperature anomaly was the comparison of air temperature in a specific year relative to the average of a normal 20-year period (2002-2021). Normal rainfall changes contained information about changes/deviations from the 30-year normal rainfall in Indonesia. Data used consisted of monthly average rainfall data from the period 1980-2010 in Indonesia. These data showed changes/deviations in rainfall patterns from normal over the past 10 years in Indonesia.

Coffee Production and Coffee Berry Borer Data

Data on coffee production and coffee berry borer attacks were sourced from the Ministry of Agriculture of the Republic of Indonesia. Data were collected directly from institutions and governments or accessed from books and websites published by relevant authorities. Coffee production data included information on coffee plantation area (hectares) and coffee harvest (tons) over the past few years (Table 1). These data were categorized based on ownership (Table 2). They also included coffee production data based on the type of coffee, whether robusta or arabica. Coffee berry borer pest attack data represented the total affected area in Indonesia over the past five years (2017-2021), measured in hectares and categorized into light attack and heavy attack.

RESULTS

Indonesia Climate Change Signs

The effect of climate change on agriculture encompassed alterations in crop yields, water availability, soil condition, and the prevalence of pests and diseases. Its effects on agriculture differed based on factors such as the specific crop, geographical location, and the extent of temperature and precipitation changes. For instance, increased temperatures, variations in precipitation, and CO_2 enrichment can either positively or negatively affect crop yields, contingent on the crop type and regional conditions.

Table 1. Indonesia Coffee Area Robusta and Arabica

Year	Robusta (Ha)	Arabica (Ha)	Robusta (%)	Arabica (%)
2005	1.112.597	89.795	93%	7%
2006	1.089.951	165.154	87%	13%
2007	1.018.573	153.884	87%	13%
2008	970.677	266.165	78%	22%
2009	946.791	270.715	78%	22%
2010	920.790	242.021	79%	21%
2011	902.341	282.626	76%	24%
2012	902.548	282.691	76%	24%
2013	879.117	314.963	74%	26%
2014	863.731	319.932	73%	27%
2015	863.626	319.619	73%	27%
2016	871.648	327.252	73%	27%
2017	859.547	332.098	72%	28%
2018	860.094	350.562	71%	29%
2019	860.438	360.703	70%	30%
2020	860.777	366.414	70%	30%

Source: Ministry of Agriculture Republic Indonesia

Table 2. Indonesia Coffee Area by Status

Year	Area (Ha)			
	Smallholders	Government	Private	Total
2012	1.187.669	22.565	25.056	1.235.289
2013	1.194.081	22.556	25.076	1.241.712
2014	1.183.664	22.369	24.462	1.230.495
2015	1.183.245	22.366	24.391	1.230.001
2016	1.198.900	23.367	24.391	1.246.657
2017	1.191.646	22.868	24.085	1.238.598
2018	1.210.656	19.923	22.247	1.252.825
2019	1.221.141	14.503	9.714	1.245.358
2020	1.227.191	13.841	9.420	1.250.452
2021	1.257.789	13.316	8.465	1.279.570

Source: Ministry of Agriculture Republic Indonesia

Global climate change also affected the climate in Indonesia. These changes were characterized by shifts in temperature and rainfall patterns. Data from the

Indonesian Meteorology, Climatology, and Geophysics Agency (BMKG) indicated a rising trend in average annual temperature. In recent years, temperatures have shown positive anomalies, meaning they tend to be higher than the 20-year average temperature (2002-2021) (Fig. 1).

In addition to rising temperatures, BMKG rainfall data also indicated changes, with noticeable differences between normal rainfall during the 1971-1990 period and the 1991-2010 period (Fig. 2).

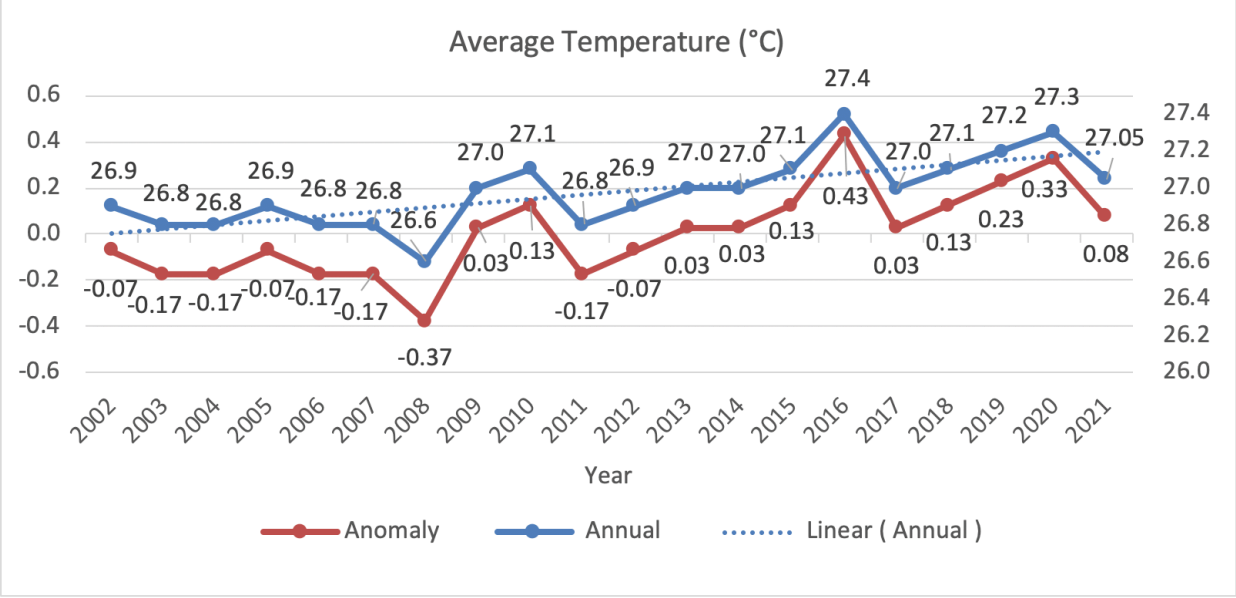

Fig. 1. Average and Anomaly Temperature (Source: BMKG).

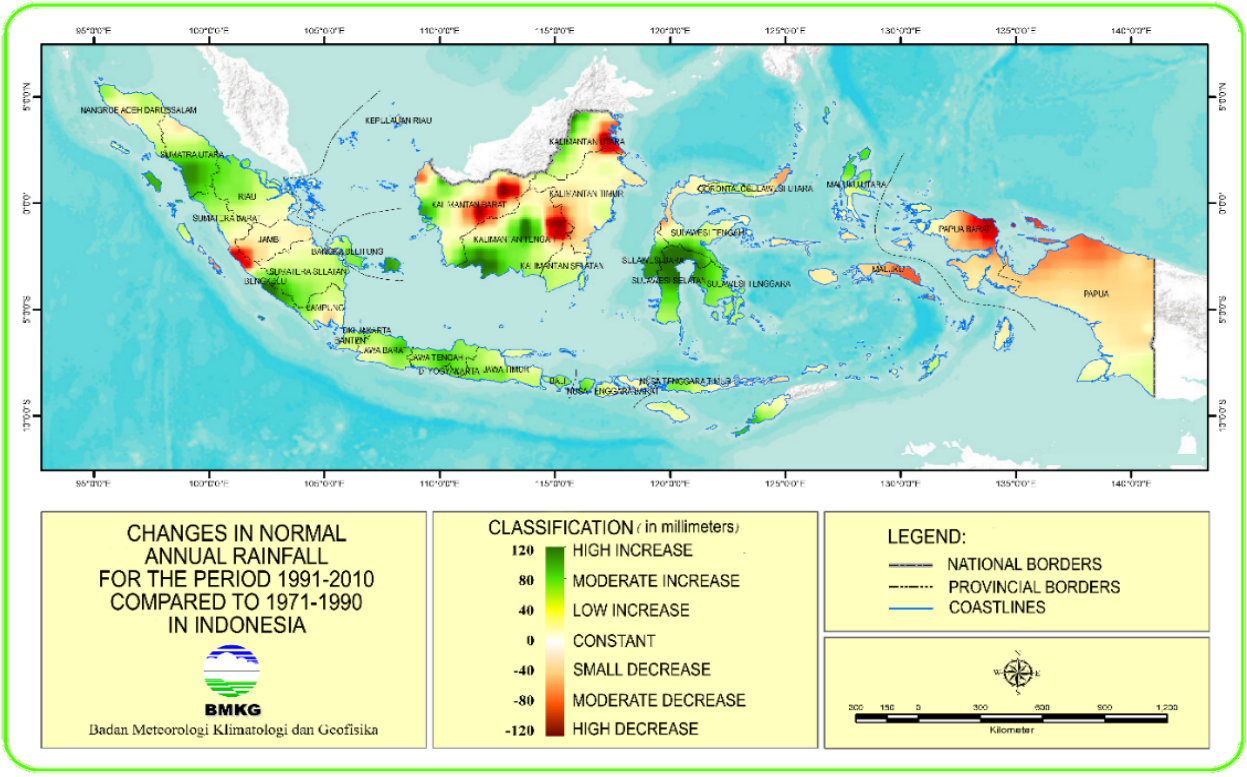

Fig. 2. Change in Normal Annual Rainfall (Source: BMKG) www.bmkg.go.id/iklim/perubahan-normal-curah-hujan.bmkg

In some regions, there is a significant increase in rainfall, indicated by a green color. However, in other areas, data showed a substantial decrease in rainfall intensity. High variations in rainfall intensity are one of the indicators of climate change. They can contribute to disasters such as floods and droughts.

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The majority of coffee production centers in Indonesia are experiencing a range of increasing rainfall, from low to high. Like other plants, coffee requires water to grow. However, excessively high rainfall can also have adverse effects on coffee. As shown in a study by Kath *et al.* (2023), high rainfall (> 750 mm) during the harvest season (October-December) could increase the probability (> 75%) of above-average coffee bean defects.

Coffee Farming Characteristics in Indonesia

Coffee farming in Indonesia is a diverse and widespread industry, where each region has its unique coffee types and flavors. Indonesia's varied landscapes offer an excellent environment for coffee cultivation, resulting in a wide range of coffee flavors that appeal to coffee lovers worldwide. Several Indonesian provinces have gained recognition as significant coffee-producing areas due to their substantial coffee production and extensive farming regions.

As of the latest available data in 2021, the top 10 provinces recognized as major coffee production hubs included South Sumatra, Lampung, Aceh, North Sumatra, Bengkulu, East Java, East Nusa Tenggara, South Sulawesi, West Java, and Central Java (Fig. 3).

These provinces are primarily concentrated on islands of Sumatra and Java, which are known for their longstanding coffee traditions and favorable growing conditions. Among these provinces, South Sumatra stands out as the foremost coffee producer, contributing substantially to Indonesia's overall coffee production.

Indonesia cultivates two primary coffee varieties, Arabica and Robusta. The primary region for Arabica coffee cultivation is the Gayo highlands located at the northern of Sumatra, while Robusta coffee is cultivated in various locations throughout Indonesia, including East Java, Flores Bajawa, and Tanahwulan village (Sugianto *et al.* ,2022; Sulaiman *et al.*, 2021).

In Indonesia, various types of coffee have been known since the 17th century, with arabica coffee being the first introduced by a Dutch individual in 1646 who brought arabica mocca beans from Arabia and sent them to Batavia in 1696.

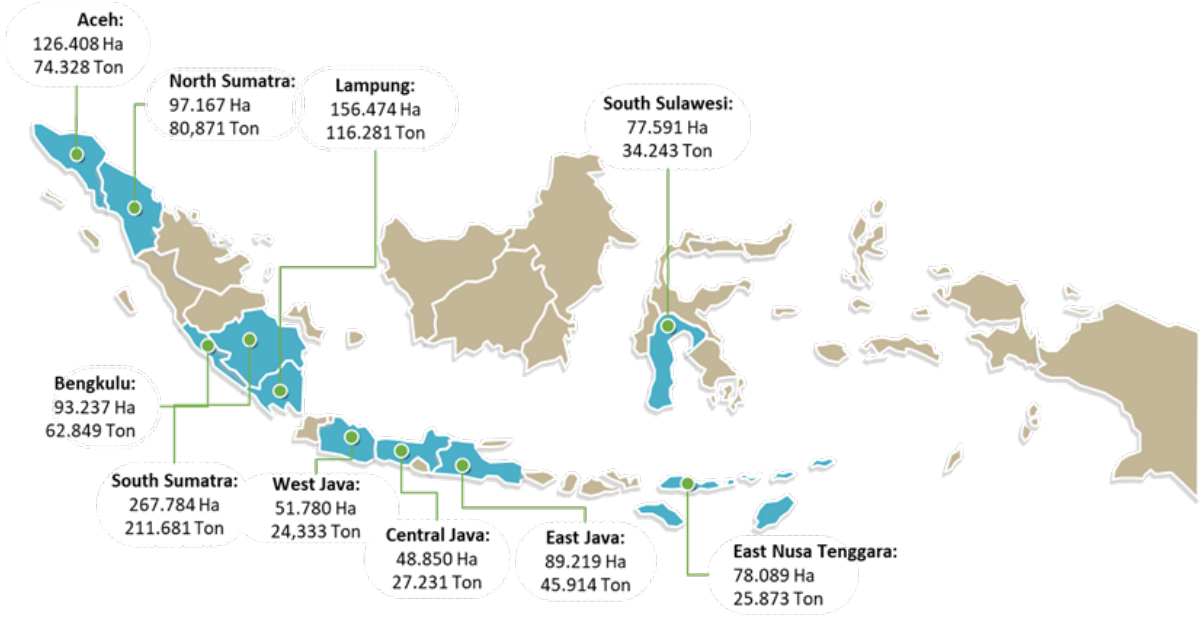

Fig. 3. Top 10 Provinces for Coffee Production Data source: Ministry of Agriculture Republic Indonesia

Although these plants initially perished due to flooding in 1699, new seedlings were introduced, which flourished around Jakarta and West Java, spreading to various regions in Indonesia. For nearly a century, arabica coffee thrived as a peasant crop from Central Java to East Java and Besuki. However, arabica coffee later declined due to an outbreak of leaf rust disease in 1876. They were only able to grow in high-altitude areas above 1000 meters. In 1900, robusta coffee was introduced to Indonesia, being more disease-resistant and having higher productivity. Robusta coffee quickly expanded. It currently dominates the total coffee cultivation area in Indonesia (Prastowo *et al*., 2010).

Coffee cultivation in Indonesia is primarily dominated by Robusta coffee, with approximately 70% of the coffee farmland in the country dedicated to Robusta. In contrast, Arabica coffee accounts for less than 30% of the total. Yearly land area data reveals that the dominance of Robusta coffee has been gradually decreasing. In fact, over a decade ago, the percentage of land dedicated to Robusta coffee exceeded 90%. This suggests that farmers have shown an increasing interest in growing Arabica coffee in recent years. Arabica coffee is a kind of coffee that requires higher production costs compared to Robusta. However, the selling price of Arabica coffee is also higher, making it more economically profitable than Robusta. Consequently, many people are starting to show interest in cultivating Arabica coffee (Ardhiarisca *et al.,* 2022).

Coffee Production and Smallholder Domination

The global coffee consumption trend continues to rise year by year according to data from the International Coffee Organization (ICO). Data indicated that global coffee consumption increased continuously, reaching 178,534,000 60-kg bags in 2022. However, the existing coffee production often falls short of meeting the demand, as seen in frequent deficits in the balance. Indonesia, the world's fourth-largest coffee producer (FAOSTAT 2023), plays a significant role in meeting global coffee needs.

Indonesia's current coffee production is still on the rise, with an average growth rate of 1.35% per year over the past decade (2012-2021). In 2021, Indonesia produced 786,191 tons of coffee on a land area of 1,257,789 hectares. Coffee production in Indonesia is primarily dominated by smallholder farms, accounting for 99.3% in 2021, with the remaining portion managed by state-owned large estates (0.5%) and private large estates (0.2%) (Ministry of Agriculture Republic of Indonesia 2022). Smallholder agriculture often faces numerous challenges. However, it remains a vital component of the industry.

Climate Change Effect on Coffee

Climate change has a big impact on coffee production. As indicated by multiple research findings, climate change exerts both direct and indirect influences on coffee production. These effects encompass alterations in suitability and capacity for coffee development, proliferation of pests and diseases, and perceptions of coffee producers. Predictions indicate that climate change will shrink regions conducive to coffee cultivation, curtail its growth, and decrease coffee yields while promoting the emergence of pests and diseases. These shifts in climate patterns will place heightened stress on coffee production systems, ultimately impacting the livelihoods of coffee producers (Guerrero-Carrera *et al*., 2020; Jawo *et al*., 2023; Piato *et al*., 2020).

The impact of climate change is being felt by major coffee-producing countries. Climate change is causing variations in temperature, moisture, rainfall, humidity, aeration, soil nutrients, light, and temperature of soil, all of which can influence the growth and production of coffee (Gokavi & Kishor 2020). Climate change can lead to a decrease in coffee quality, a decrease of coffee production, shifts in regions where coffee is grown, and a rise of coffee-related pest and disease issues.

Research about Effects of Climate Change on Indonesia Coffee

Since Indonesia is one of the primary coffee-producing nations, the progress of coffee in Indonesia is just as crucial as in other countries. Thus, effect of climate change on coffee in Indonesia have also become a significant focal point in several studies.

Research by Grüter *et al.* (2022) based on multiple climate change scenarios has predicted that by 2050, suitable coffee growing areas in Indonesia will decrease by almost half. A study by Boer *et al.* (2019) in Toba, North Sumatra has indicated that by the mid-21st century (2050s), under climate scenarios of RCP4.5 and RCP8.5, suitable coffee production areas will significantly decrease. Average yields are projected to decrease by 25% to 75% compared to the current yield. However, highlands that are currently unsuitable for coffee cultivation are expected to become suitable with higher yields. This change will also alter the timing of coffee flowering and harvesting seasons in Toba, with an increased threat from coffee berry borer.

Schroth *et al.* (2015) have focused on Indonesia's main Arabica coffee production regions in Sumatra, Sulawesi, Flores, Bali, and Java. Their study suggests that, due to temperature increases and changing rainfall patterns of different islands, the total area with suitable conditions for coffee production will significantly decrease by 2050. Nevertheless, there will still be more lands with the right climate and topography for coffee cultivation outside protected areas than currently utilized, although these areas will not be in the same locations.

Research by Sujatmiko and Ihsaniyati (2018) has revealed that climate change, characterized by high rainfall causing flowering failure and prolonged drought preventing bloom, can lead to decreased coffee production and income for smallholder farms. Productivity plays a crucial role in the economics of coffee plantations, especially for smallholder farmers in Indonesia with less than 10 hectares of land. Reduced productivity will adversely affect farmers' income.

Attack by Coffee Berry Borer Pest

Coffee berry borer attacks coffee by boring into coffee berries. Females create an opening in the coffee berry through the disk.

The initial stage of infestation begins with a female colonizer entering the berry through a circular entrance hole, which typically measures between 0.6 to 0.8 mm to 1 mm in diameter. Inside the seed, females construct galleries where they lay their eggs (Vega *et al.*, 2015). After hatching, female coffee berry borers go through two larval stages, different from males which only have one larval stage (Gómez *et al.*, 2015).

The development of CBB attacks in Indonesia can be observed from existing case trends. Data obtained from the Ministry of Agriculture for CBB attacks over five years from 2017 to 2021 showed an increasing trend (Fig. 4).

The affected area by CBB has increased, especially for heavy attacks. As for light attacks, a significant increase was observed in the year 2018.

Climate Change Effect on Coffee Berry Borer

The attack of coffee berry borer (*Hypothenemus hampei*) can be influenced by many factors, among which climate has a significant impact. Specific research, such as the study by Kaimuddin *et al.*, (2021), has identified climatic factors, particularly minimum and average temperatures, that could significantly influence coffee berry borer (CBB) infestations. Climate factors explained 60.90% of the variation in pest attacks on coffee plants, while other unexamined factors accounted for the remaining 30.10% of the variation. While specific research studies about the impact of climate change on coffee berry borers in Indonesia remain limited, studies on the influence of climate components such as temperature and rainfall on coffee berry borers or research from other countries can provide valuable reference points.

Rising temperatures caused by climate change can cause an increased incidence of coffee borer and leaf rust disease, which can cause a 50% decline in coffee production (Agegnehu *et al.*, 2015). Research has examined thermal resilience of coffee berry borer. Projections have estimated that climate change will have a significant and adverse effect on this pest (Jaramillo *et al.*, 2009). Possible spreading of agricultural pests has been assessed under projected climatic scenarios. Results indicate that variables associated with precipitation are more influential than those related to temperature in determining the pests' geographical Jaramillo *et al.* (2009) have conducted a study on coffee berry borer's thermal tolerance and its potential consequences in a changing climate. Their model predicted that a temperature rise of 1–2°C could result in a higher number of generations, increased spreading, and greater loss caused by coffee berry borer. Additionally, a temperature increase of 2°C or more might potentially cause alterations in the pest's distribution.distribution (Kutywayo *et al.*, 2013).

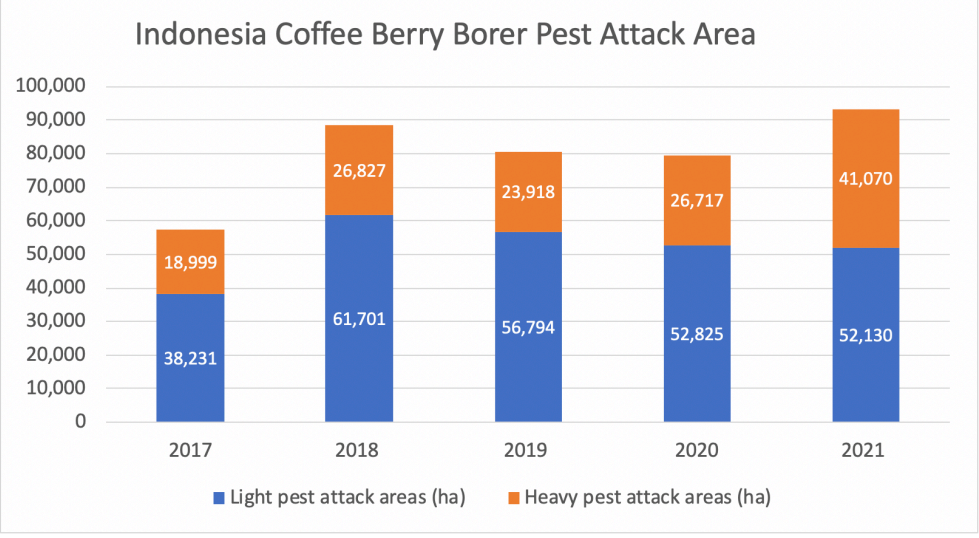

Fig. 4. Indonesia Coffee Berry Borer Pest Attack Area

Discussion

Effects of climate change can impact various sectors, particularly agriculture such as coffee cultivation. Coffee plants are sensitive to their environment. Climate changes can affect coffee growth, production yields, and quality. Additionally, climate change can influence the activity of pests that attack coffee plants. Research on climate change has been intensive lately, with some studies attempting to measure impacts of past climate changes and predict future consequences.

Climate change's impact on agriculture, an essential sector concerning food availability and livelihoods for many, has been the subject of extensive research. Various crops, including coffee, have been a focus of these studies, examining effects of climate change on production, coffee quality, growth patterns, and pest attacks. In Indonesia, a significant coffee-producing country, several researchers have explored how climate change can affect coffee production.

Based on gathered literature, it is evident that climate change will pose a potential threat to coffee production and the CBB pest in coffee-producing countries, including Indonesia. In broad terms, impacts of climate change on coffee production involve unsuitable land conditions for coffee growth. Simultaneously, effects of climate change on CBB stem from changes in its behavior. Both effects can lead to a decrease in coffee production and risk the availability of coffee to meet both national and global demands. If this continues, coffee may become a scarce and hard-to-find commodity in the future.

Characteristic Factors in Indonesian Coffee Production

The dominance of robusta coffee in Indonesia is slowly decreasing as farmers' interest in cultivating arabica is on the rise. Despite challenges associated with arabica cultivation, such as its susceptibility to climate issues and pests such as CBB, its competitive prices are attractive to farmers. The increase in arabica coffee plants needs to be accompanied by anticipation of issues related to arabica coffee. The higher proportion of arabica compared to robusta has the potential to make coffee production in Indonesia more susceptible to climate change and CBB infestations.

Another characteristic of the coffee industry in Indonesia is its dominance by smallholder farmers. Smallholder farmers have distinct characteristics that differ from large companies. They are often more vulnerable to livelihood shocks, including climate change and pests, putting their situations at risk. When we talk about impacts of climate change, especially in Indonesia, we need to make sure we focus on these smallholder farmers. Steps we take should reach many small farmers who spread across Indonesia.

Coffee farmers in each region have unique characteristics, as is the case in Indonesia. There are many other characteristics, such as those related to adapting to technology, social aspects, economic systems, and so on. When considering preventive measures against impacts of climate change, it is advisable to take these characteristics into account. This way, actions taken will be more effective and targeted. By considering these characteristics, we can also identify weaknesses and predict potential problems that may arise.

Government's Efforts to Boost Climate-Resilient Agriculture

The government, through the Ministry of Agriculture, has issued a General Guideline. This agricultural sector guideline aims to provide direction and enhance understanding in identifying impacts of climate change while promoting and directing efforts and action programs for agricultural adaptation. Along the way, this General Guideline has received a positive response from both government authorities and farmers as implementers.

At the implementation level, farmers have benefited from infrastructure support. For example, they have benefited from the establishment of "Sekolah Lapang Iklim" or Climate Field Schools, which serve as hands-on training platforms where farmers can receive practical guidance and training on climate-resilient agricultural practices. The "Sistem Informasi Kalender Tanam Terpadu" (Integrated Cropping Calendar Information System) provides farmers with a comprehensive calendar that incorporates various factors such as climate information, planting schedules, and crop selection. "Jaringan Informasi Iklim Pertanian" or Agricultural Climate Information Network plays a crucial role in disseminating real-time climate data, weather forecasts, and agricultural advisories to farmers. "Sistem Peringatan Dini" or Early Warning System is instrumental in alerting farmers to potential climate-related threats such as extreme weather events.

The government is also involved in creating innovative technology and crop types that can handle climate change. They also work on improving farming infrastructure such as irrigation systems. By investing in research and better farming techniques, the government can make farming more sustainable and productive. This way, they can give farmers the right tools to succeed in a changing climate while also strengthening important farming facilities.

Coffee Farmers' Awareness and Response to Climate Change Challenges

From the farmers' perspective, they already recognized risks posed by climate change. For instance, a survey conducted by Mutolib *et al.* (2021) in West Lampung

Regency indicated that coffee farmers were conscious of the effects of climate change. Among them, 60% had acknowledged climate change within the past 1-5 years, while 20% had been aware of it for more than 5 years. In terms of taking steps to mitigate these changes, 25% of coffee farmers are actively engaged in climate change mitigation efforts. These practices include the use of superior coffee varieties, the planting of shade trees, adjustments in coffee spacing, the creation of vents, and the utilization of leftover coffee husks to enhance soil fertility and moisture. Farmers have planted 14 different types of shade trees, including both legumes and non-legume trees. Interestingly, "Petai" (Parkia speciosa) is the most chosen shade tree in coffee plantations, with 45% of respondents opting for it.

Control Method of Coffee Berry Borer

With increasing potential for CBB attacks, pest control methods need to be enhanced. Integrated pest management utilizing various effective control techniques can be employed. Innovation becomes crucial to discover potential new control techniques and reduce dependence on pesticides, which often have adverse environmental effects for Indonesia as the third-largest user of pesticides in agriculture after Brazil and the United States (FAO 2023).

Research on CBB pest control techniques has been conducted in Indonesia. Some studies have employed more environmentally friendly methods such as the use of attractants and biological agents, showing promising results. For instance, a study by Tobing *et al.* (2022) has found that using attractants from extracted coffee beans and pericarp (outer skin) can effectively control CBB when employed in traps at different heights. The most successful trap height was at 0.5 meters, capturing 8.50 adult CBBs. Another study by Siswanto & Rismayani (2022) has explored the use of biological agents, specifically entomopathogens. Their research has demonstrated that applying pathogenic fungi such as *B. bassiana* and *L. lecanii* on infected coffee cherries can reduce the development of cherries affected by CBB pests while increasing the number of unaffected, healthy cherries.

Continuous improvement and adjustment of pest control systems are necessary as part of climate change adaptation. This is crucial because, with climate change, patterns and severity of pest attacks can change. Therefore, research in this field needs to continue to observe changes in pest behavior due to climate change while exploring more effective pest control methods.

Conclusions

The coffee production landscape in Indonesia is undergoing significant changes in response to impacts of climate change. One of the key obstacles confronting coffee producers in the nation is the influence of climate change on the occurrence and habits of coffee berry borer (*Hypothenemus hampei*), a significant pest that impacts coffee plantations.

Indonesia's coffee-producing regions are experiencing shifts in temperature and precipitation patterns. These changes have direct implications for coffee cultivation and the life cycle of CBB. As an effect of altered climate conditions, CBB is becoming more resilient and adaptable, posing a greater threat to coffee plantations. Increased temperature and humidity encourage the increase and excess of this destructive pest. The changing climate not only impacts the prevalence of CBB, but also influences overall coffee yield and quality. Increasing temperatures, extreme weather, and unpredictable rainfall can reduce coffee production.

The rising interest in cultivating arabica coffee over robusta in Indonesia driven by its competitive prices poses challenges due to susceptibility to climate issues and CBB. The dominance of smallholder farmers in the Indonesian coffee industry adds a layer of vulnerability due to their distinct characteristics and susceptibility to livelihood shocks from climate change and pests.

Indonesia has implemented a comprehensive approach to enhance climate-resilient agriculture, receiving positive feedback. Government efforts include practical measures such as Climate Field Schools and an Integrated Cropping Calendar Information System. Farmers, recognizing climate change risks, are actively adopting mitigation practices, although challenges persist in embracing Climate Smart Agriculture. Ongoing research is crucial to adapting and improving pest control strategies amid changing climate patterns. Collaborative efforts of the government, farmers, and ongoing research underscore a collective commitment to addressing climate challenges in Indonesia's coffee industry.

Conflict of Interest

The authors declare that they have no competing interests.

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