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The Role of Certificates and Labels for Cocoa in the Face of Climate Change: A Scientific Review

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Abstract

Climate change threatens cocoa quality, raising concerns regarding sustainable premium cocoa production. Evaluating the effectiveness of certification standards is imperative to address this concern effectively. A multi-stage method was employed for a systematic review of 39 peer-reviewed articles to highlight the impacts of climate change on the biophysical environment of cocoa and its implications for adapting Geographical Indications (GIs). Additionally, a comprehensive review was conducted on climate-relevant standards of certificates in Ecuador, Indonesia, and Ghana. The findings of this study provide practical insights into possible difficulties that cocoa-producing countries may encounter in maintaining the distinctive flavours and quality trademarks of cocoa in the face of changing climate. Moreover, the findings emphasize the need for producer countries to prioritize viable adaptation and product differentiation strategies that meet sustainable marketing standards to protect GIs or place-based intellectual property. Furthermore, the findings indicate certificates require effective multi-level climate change management and environmental-social-governance principles that promote scientifically proven mitigation strategies, such as increasing soil organic carbon, zero deforestation, and reducing emissions while striving to leverage local adaptation policies to reduce location-specific vulnerability. Finally, certificates can accelerate the expansion, intensification, and redistribution of sustainable production for gains that outweigh the inconveniences caused by climate change.

Keywords

Adaptation, Biophysical Environment, Climate Change, Cocoa Certificates, Environmental Social Governance, Geographical Indications, Mitigation

1. Introduction

Prior studies on climatological shift in cocoa-producing countries have primarily focused on climate change vulnerability of cocoa, potentially leading to varietal extinction, biodiversity loss, and high cocoa mortality (IPCC, 2007; Schroth et al., 2017; Bunn et al., 2018; Fountain & Hütz-Adams, 2022). The climatological shift may exacerbate changes in water, soil, air, pest, and disease conditions, affecting cocoa quality (Schroth et al., 2016). Due to the potential shifts in biophysical conditions, sustainable production is crucial to maintaining the quality definitions of cocoa. Cocoa (*Theobroma cacao*) is distributed throughout the range of 15˚N/S - 20˚N/S latitude and demands a limited set of biophysical and climatic conditions for optimal growth (Anim-Kwapong & Frimpong, 2006; WCF, 2014; Schroth et al., 2016). Extreme rainfall and high temperatures pose significant risks to cocoa cultivation systems (Vaast & Somarriba, 2015; Niether et al., 2017b; Niether et al., 2018). The average temperatures of 18˚C - 21˚C and 30˚C - 32˚C considerably impact the quality and size of cocoa in commercial and sustainable farming (Bunn et al., 2018; ICCO, 2013). The quality and yield of commercial cocoa are mainly determined by continuous precipitation and stable soil moisture content (Schroth et al., 2016). Although cocoa production is limited by a minimum temperature of 10˚C in the tropics, elevated temperatures in dry seasons are the main stressors for cocoa (Schroth et al., 2016; Bunn et al., 2018). Climate change threats to quality definitions of cocoa may lead to the loss of premium cocoa, potentially affecting market penetration and presumed "geographical indications"[1] (Tscharntke et al., 2015; Clark & Kerr, 2017). It is worth noting that socio-political and economic constraints hinder shifting natural production locations within and between producer countries (Schroth et al., 2016; Clark & Kerr, 2017). Producer countries face the challenge of supplying quality cocoa sustainably while maintaining quality trademarks and monopoly rent amidst climate change. A potential climatological shift disproportionately impacts the cocoa supply chain more than other commodities (ICCO, 2013; ICCO, 2014; FAOSTAT, 2014; Gateau-Rey et al., 2018).

Studies show that cocoa-growing regions emit over 1.4 billion tons of CO_2 annually due to substantial land use emissions (Eagle et al., 2012; Gockowski & Sonwa, 2011). Greenhouse gas emissions, including land use and fossil fuels in cocoa supply chains, significantly alter dry-wet cycles and potentially contribute to global warming[2]. Scientific viewpoints suggest prioritizing carbon sequestration

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[1] Geographical Indications (GIs) are intellectual property that recognize a food, beverage, or artisan product as holding distinct properties based on geographic origin (Clark & Kerr, 2017). Protected Geographical Indication (PGI) or Protected Designation of Origin (PDO), "[…] "designation of origin" is a name which identifies a product: (a) originating in a specific place, region or, in exceptional cases, a country; (b) whose quality or characteristics are essentially or exclusively due to a particular geographical environment with its inherent natural and human factors; and (c) the production steps of which all take place in the defined geographical area" (European Council, 2012).

[2] Agricultural production is associated with greenhouse gas (GHG) emissions from activities that cannot be decarbonized. For example, agricultural management of soils, digestive processes in ruminants, and storage of farm manure generates GHG including methane (CH_4), nitrous oxide (N_2O), and carbon iv oxide (CO_2) emissions (Eagle et al., 2012; IPCC, 2014).

and conserving soil organic carbon stocks on cocoa lands can protect biodiversity and ecosystem services, resulting in low greenhouse gas emissions (Burney et al., 2010; Eagle et al., 2012). The main aim of this study is to explore the potential biophysical shift influenced by climate change in Ecuador, Indonesia, and Ghana and the resulting implications for cocoa quality attributes. Global north markets, states, and civil societies create certificates and standards for producers to improve working conditions and the environment, allowing access to specific markets and targeting socio-economic and environmental issues (Ellis & Kaene, 2008; Tscharntke et al., 2015; Kroeger et al., 2017). As demand for certified cocoa increases, farmers are motivated to adopt more climate-friendly practices to access global markets. It is worth noting that certificates and labels promote scientifically proven principles for environmentally friendly crop production and ensure transparency in the crop value chain (Tscharntke et al., 2015; ICCO, 2014). Moreover, certificates and labels demonstrate commitment to environmental protection and incentivize farmers to improve ecosystem services (Milder et al., 2011; Steijn, 2016; Wijaya & Glasbergen, 2016). Standards of certificates and labels include economic and ecological measures and regular reporting of producers' adherence to ethics (Bethge, 2014; Jermann, 2016; Kroeger et al., 2017). It is worth mentioning that effective certification relies on robust verification systems. To reach a wider audience, certificates require farmers to form cooperatives for training and improving production standards. Certification outcome offers a consistent logic to evaluate the best standards in sustainable agricultural policy or environmental, social, and governance (ESG) aspects. ESG-Certification outcome pillars, the link between them should be recognized as a key strategic priority for producer countries. However, media and academic criticism show that certificates do not produce the desired outcomes for cocoa producers or the environment. Recent environmental reports indicate that intensified deforestation occurs in certified cocoa-growing regions in West Africa, causing a biophysical shift and unsustainable production (Tscharntke et al., 2015; Waarts et al., 2015; Higonnet et al., 2017; Ingram et al., 2018; Kateman, 2019; Meemken et al., 2019: Whoriskey, 2019; World Wildlife, 2019; Mighty Earth, 2022).

The trajectory in certified cocoa-growing regions suggests that the indirect support of cocoa consumers for transparency and genuine climate protection through certificates and labels does not necessarily guarantee clear environmental benefits. Despite the existence of extensive literature on various aspects of climate change, the ethical dimension of cocoa certification regarding climate change has been relatively overlooked. This is rather surprising considering the nature of climate change and the questions it poses. This present study draws from academic sources to conduct an in-depth systematic review of the impacts of climate change on cocoa quality attributes, in addition to how the code of conduct of leading cocoa certificates can influence the sustainable supply of premium cocoa in the face of climate change.

This approach allows an explorative study of the nexus between certification standards, sustainable practices, and outcomes and how this linkage puts producers on the path toward climate resilience and ESG certification. In doing this, the present study adds to literature by evaluating climate-related standards for climate change adaptation and mitigation, focusing on the significance of sustainable cocoa production. Moreover, this study underscores the lack of evaluation of primary standards for effective climate change adaptation and mitigation design, the unclear responsibility of certificates regarding environmental improvements, and the knowledge gap on the impact of climate change on quality definitions of cocoa. Furthermore, the study considers a knowledge gap regarding marketing and management solutions for preserving geographical indications (GIs). Finally, this study explores the huge policy challenge of lowering greenhouse gas emissions in producer countries.

2. Methodology

2.1. Systematic Review

A systematic literature review was conducted on the impact of climate change on the quality definitions of cocoa in Ecuador, Ghana, and Indonesia using data from various search engines (**Table 1**). This systematic review followed the "preferred reporting items for systematic reviews and meta-analyses" (PRISMA) standards (**Figure 1**) (Page et al., 2021). The PRISMA checklist is detailed in the Appendix. The systematic literature search and the application of inclusion

Table 1. Database and Internet search protocol for studies on cocoa.

Search terms	**Search strategy**	**Filtering conditions**	**Database**	**Initial references***	**Total references**
Adaptation strategies of Rainforest Alliance AND Fairtrade certificate. Effects of cocoa certification, climate mitigation and adaptation strategies linked to: *cocoa, *ecosystem services, *soil, *biodiversity, *shade trees, *agroforestry, *pest, *climate change, *Ghana, *Indonesia, *Ecuador	Database: All terms searched as keywords in title, abstracts & references Date: 2008-2023	Evidence of impacts of Rainforest and Fairtrade certification in identified countries from 2008-2023	Google Scholar	459 (15)	3
			Web of Knowledge	381 (3)	1
			Science Direct	102 (3)	1
			Scopus	114 (2)	1
Effects of climate change OR increased temperature, precipitation, rainfall, evapotranspiration, drought linked to: *biophysical, *biological, *physical, *environment, *pest, *soil, *adaptation, *mitigation *ecosystem services, *biodiversity, *shade trees, *agroforestry, *geographical indication, *Ghana, *Indonesia, *Ecuador	Database: All terms searched as keywords in title, abstracts & references Date: 2000-2023	Selected studies containing all English publications on climate change influences on cocoa that match the inclusion criteria	Google Scholar	373 (56)	19
			Web of Knowledge	182 (14)	2
			Science Direct	89 (23)	3
			Scopus	109 (8)	5

*Figures in parenthesis are reports or records assessed for eligibility ($n = 124$).

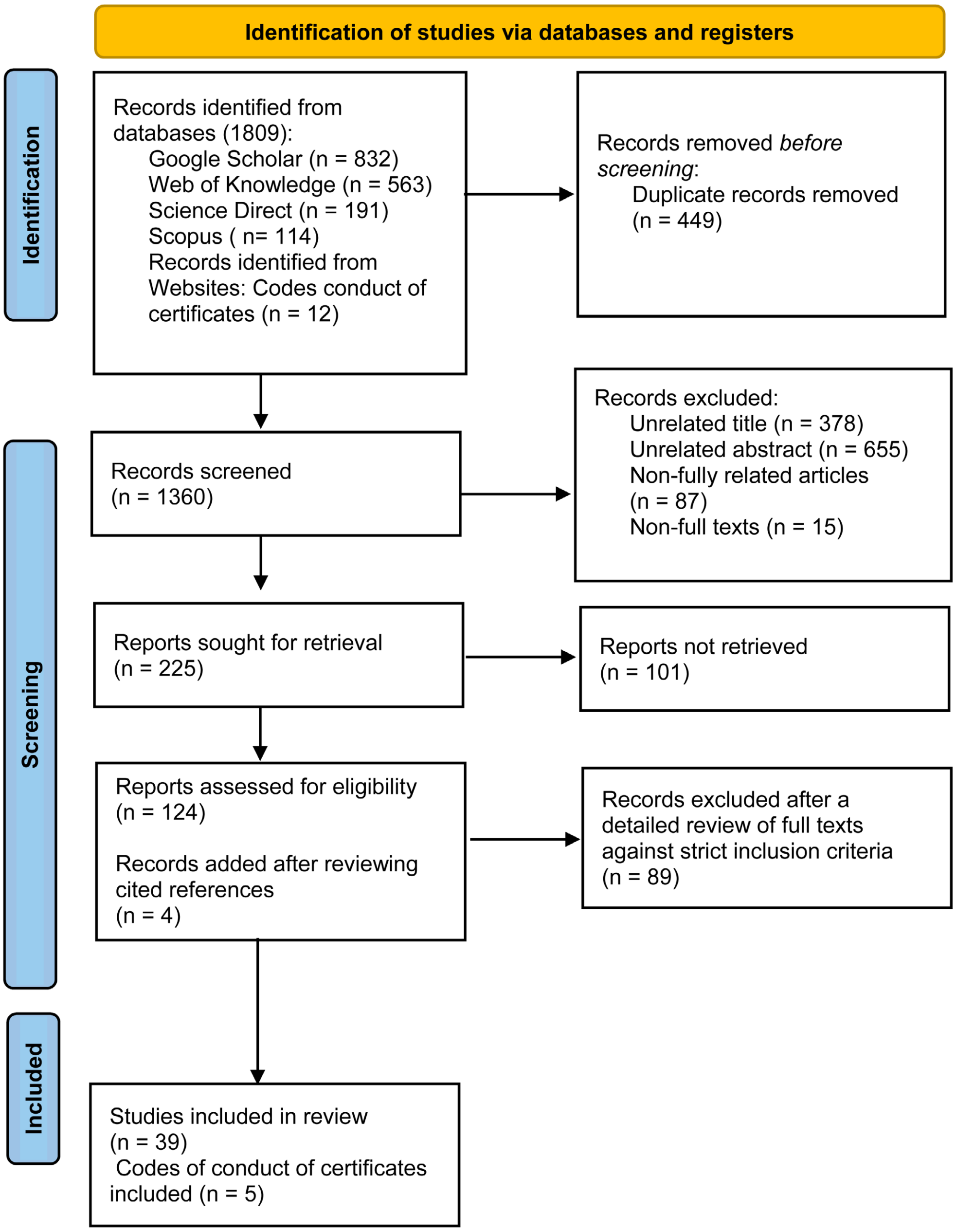

Figure 1. PRISMA flow diagram of the study selection.

criteria are consistent with review studies that identified an appropriate subcategory of literature (Kilroy, 2015; Ezzine-de-Blas et al., 2016; Page et al., 2021). Search terms, phrases, titles, and abstract screening were performed on 1,809 articles using the following inclusion or filtering criteria:

1) Studies that examined the effects of climate change on soil, shade, drying, cocoa variety, and pests in the identified countries from 2000 to 2023.

2) Studies with climate trends in identified countries from 2000 to 2080.

3) Studies with an explicit focus on predictions of climate change impact on precipitation, temperature, biodiversity, ecosystem services, soil, shade, drying, cocoa variety, and pests.

4) Studies that explicitly link the effects of adaptation and mitigation strategies of cocoa certification in Ghana, Indonesia, and Ecuador to the following: cocoa variety, pest, water, air, soil, ecosystem services, biodiversity, shade trees or agroforestry, and climate change from 2008 to 2023.

5) Original research (quantitative and qualitative reports) and all existing major English publications, review papers, and grey literature.

Additional literature was discovered by searching for references in the first set of documents. A final data extraction on 39 of the studies was performed.

This systematic review offers a unique opportunity to:

- Explore the unaddressed, multifaceted issues of climate impact on the quality attributes of cocoa and the implications for sustainable geographical indication.
- Perform case studies and address questions relating to the minimum biophysical and environmental conditions required for producing quality cocoa in producer countries.
- Delve into potential adaptation strategies and scientific interventions to mitigate the adverse consequences of climate change on premium cocoa production, underscoring the importance of collaborative efforts among researchers, policymakers, and certificates to foster resilience and develop sustainable environmental practices within the cocoa supply chain.

2.2. Scanning and Analyzing Codes of Conduct of Certificates

This study explores climate-related standards for cocoa production in Ecuador, Ghana, and Indonesia, aiming to understand climate mitigation and adaptation standards for sustainable premium cocoa production, focusing on certificates' potential for climate adaptation. The standards are designed to assist producers in adjusting to the effects of climate change (e.g., standards on soil management, water conservation, shading, and pest management). A literature review was conducted to investigate the codes of conduct, including, but limited to Fairtrade Climate Standard (pp. 40-48) (expected date of next review was 2020), the Fairtrade Standard for Hired Labour (2005: 41-52) (expected date of next review was 2019), and the Fairtrade Standard for Small-Scale Producer Organizations (pp. 17-33) (expected date of next review is 2024) (Fairtrade International, 2016a; Fairtrade International, 2016b). Other standards examined include the Rainforest Alliance Sustainable Agriculture Standard (2019: 4-51) (applicable for Medium-Large Farms, draft Standard V2.0 for external consultation) and Rainforest Alliance Sustainable Agriculture Standard (SAN, 2017: 37-48) (Rainforest Alliance, 2019; Rainforest Alliance, 2017). A filtering criterion was established with a strict focus on environmental standards that only applied to crop production.

Moreover, all crop management standards required of producers to adapt tree crops to climate change, including shading or agroforestry, soil conservation, water and pesticide management practices were extracted. Furthermore, focusing on crop management standards and adaptation impacts, the findings of scientific studies on Rainforest Alliance and Fairtrade certification on cocoa production and the environment were summarized (**Table 1**). Another focus was to examine the climate change mitigation initiatives of cocoa certificates. As such, this study explored environmental standards, focusing on mitigation initiatives appropriately specified to reduce greenhouse gas emissions. The essential adaptation and mitigation standards associated with the identified certificates were catalogued.

3. Results

3.1. Study Selection

In this section, the major findings drawn from literature and documents containing standards of certificates are summarized. The application of search criteria for peer-reviewed studies resulted in 753 total documents. An initial assessment of abstracts, titles, and full articles and removing duplicates reduced this number to 124. The final evaluation against the inclusion criteria reduced this number to 29. Four more texts were identified after reviewing the cited references in these 29 articles. The selection criteria brought the number to 33 publications for data extraction: 19 for Ghana, 9 for Indonesia, and 5 for Ecuador.

An application of a search strategy for studies on certification impacts resulted in 1056 total documents. An initial assessment against the inclusion criteria reduced this number to 23. A subsequent, more detailed review, including a review of the full articles that only focused on the observed impacts of certification programmes in identified producer countries, brought the number to 6. Many publications were unsuitable for the review because this present retrospective study focused on management practices and voluntary standards of cocoa certificates for climate change adaptation and mitigation. In addition, the review was limited to the potential influence of local climate on geographical quality definitions of cocoa, which provides traditional producer countries with recognized "geographical indications." It should be noted that the final number of 39 articles selected for the review did not include 5 independently scanned codes of conduct of certificates.

3.2. Climate Model Projections in Cocoa-Producing Countries

The findings suggest variations in the climate patterns in leading producer countries, with projected effects varying among the countries. All three countries are projected to have higher temperatures based on the analyzed climate change model (Hadiani et al., 2011; Läderach et al., 2013; Schroth et al., 2017; CCKP, 2018). On a regional basis, there is an unambiguous indication of a consistent rise in annual and monthly temperature and precipitation (**Table 2**). The most severe effects are anticipated in cocoa-producing locations in Ghana and Ecuador (above 2˚C). Despite the existing high temperatures associated with the El Niño effect, Indonesia's climate is predicted to be relatively higher (1.7˚C high). Projections show that the annual rainfall in Ecuador and Indonesia will rise significantly. As a result, the climatic suitability of the current cocoa-growing regions in all three nations will reduce considerably by 2050 (Table 2).

3.3. Case Study on the Biophysical Influences of Climate Change in Producer Countries

In this subsection, the study explores the impact of climate change on biophysical conditions in cocoa-producing countries, focusing on selected producer countries (Table 3).

Table 2. Summary of climate projections for producer countries from 2020 to 2080.

Country	Key findings of climate model projections
Ghana	The average monthly maximum temperature is estimated to rise from 33.1˚C to 35.6˚C. The average monthly minimum temperature is estimated to rise from 20.6˚C to 22.2˚C. The warmest quarter is projected to be 2.0˚C to 2.3˚C hotter in 2050. A shorter projected dry season and general temperature rise will increase evapotranspiration. Precipitation is expected to decrease from 2020 to 2080. The estimated change in precipitation distribution will not compensate for the increase in evapotranspiration. In another scenario, an expected increase in annual precipitation could shorten the dry season in the 2050s. Considering the current conditions, little difference in the longer-term hydrological conditions within cocoa-growing regions is expected. Due to high temperatures, the shorter dry period will offset the projected increase in water demand due to heat stress.
Indonesia	In Sulawesi Island, Bali, West Java, North Sumatra, and Papua, the average temperature is projected to increase by 1.7˚C. Rainfall, which is estimated to increase by 2% to 3% each year, will lead to La Niña. Intense rainfall within a shorter rainy season will lead to increased flood risk. In the 2020s, the mean temperature is estimated to rise by 0.36˚C to 0.47˚C.
Ecuador	From 2030 to 2049, the average annual temperature is projected to rise by 2˚C to 3˚C. By 2050, the estimated mean annual temperature will rise by 1.9˚C, while precipitation will increase by 150.4 mm. A predicted increase in the frequency of negative thermal anomalies in the equatorial Pacific will lead to unexpected rainfall and prolonged dryness (i.e., La Niña and El Niño), leaving the entire coastal and agricultural areas with exceptional warmth.

Table 3. List of cocoa-producing countries, certificates, and varieties.

Country	Certificates/Labels	Variety
Ghana	Rainforest Alliance, Fairtrade,	Hybrid, Teteh Quarshie, and Amazonia
Indonesia	Rainforest Alliance, Fairtrade, Utz	Kakao Lindak
Ecuador	Rainforest Alliance, Fairtrade, Utz	Nacional, Arriba

3.3.1. Ghana: Hybrid Cocoa

Hybrid cocoa is the dominant variety in Ghana. Williams (2009) shows that high-quality, premium-priced Ghanaian cacao beans are about 10% higher than the world market average market price due to favourable climatic conditions in cocoa-growing areas. Rising temperatures, potentially reaching 38˚C in cocoa-growing regions within West Africa's cocoa belt, pose a significant threat to Ghana's bulk cocoa (FAO, 2007; Asante & Amuakwa-Mensah, 2015; Schroth et al., 2016). Ghana's cocoa production, reliant on less advanced technology, is vulnerable to climate change, with the average temperature expected to rise by up to 2˚C in 2050, which would result in an enhanced drought (**Table 2**). Higher temperatures may increase cocoa tree evapotranspiration, leading to severe water stress on the trees (Schroth et al., 2016). The situation suggests that cocoa plant water requirements may change due to potential droughts, which could impact cocoa pod quality and potentially lead to reduced yields. The drought stress may cause a concentration of quality cocoa production in a few regions of Ghana (Schroth et al., 2016). By 2050, the Western region, Eastern region, and Ashanti region will be the most climatically favourable for cocoa production (Läderach et al., 2013; Asante & Amuakwa-Mensah, 2015; Schroth et al., 2016). The existing favourable climate in these areas has influenced cocoa productivity and quality. A few cocoa-growing regions, such as Volta, Central, and Brong-Ahafo could be adversely affected by a change in climate and biophysical conditions (Schroth et al., 2016). The situation is the case for Ghana as cocoa yields along climatic gradients and increases significantly from less climatically favourable locations to more favourable humid locations (Abdulai et al., 2020). Climate change and longer growing seasons can increase cocoa pests and pathogens, causing seasonal changes in host resistance and disease physiology (Anim-Kwapong & Frimpong, 2006; Hütz-Adams et al., 2016). Certain shade trees in cocoa-growing regions in Ghana exhibit limited resilience to extreme climates, a location-specific issue due to the varying impacts of climate on shade trees (Abdulai et al., 2018b). Kongor et al. (2019) demonstrated that soil quality in six cocoa-growing locations in Ghana varies due to precipitation, with the Western region having the highest quality, followed by Brong Ahafo and Volta regions. Ghana's soil fertility status, particularly in Ashanti, Central, and Eastern regions, is characterized by low suitability for cocoa cultivation due to changes in pH and CEC (ibid.). The Western, Brong Ahafo, Ashanti, and Eastern regions are semi-deciduous zones of high rainfall. The optimal soil conditions required for cocoa growth are more prevalent in these areas (Issaka et al., 2013). It is worth noting that increased rainfall (on average, 44 mm per day) leads to soil erosion, which affects crop production in Ghana (Climate Change Profile of Ghana, 2018). Changes in biophysical characteristics impact Ghana's premium cocoa, with Ghana's cocoa production declining from 969,000 tons in 2016/2017 to 900,000 tons in 2018/2019 (ICCO Statista, 2019).

3.3.2. Indonesia: *Kakao Lindak*

Indonesia's cocoa-growing areas are predicted to experience significant climate change in the coming decades, potentially overwhelming the production of Kakao Lindak on the island of Sulawesi, which accounts for 75% of the country's cocoa production (**Table 2**). Indonesia's cocoa areas experience warmer climates than West Africa, indicating no significant environmental risks due to the absence of noticeable adverse impacts. However, periodic droughts in main production centres in Eastern Indonesia associated with El Niño and ENSO cause prolonged drying, leading to seedling mortality, cocoa yield loss, and increased witches' broom disease infection rates. Expansion of farms leads to deforestation, causing increased temperatures and reduced rainfall, affecting soil moisture content and biodiversity (Sari et al., 2007; Hadiani et al., 2011; Witjaksono, 2016). Cocoa production in areas without shade worsens due to shorter dry seasons, causing pod failure and affecting bean yield and size (Witjaksono, 2016). Prolonged drying and extreme rainfall significantly impact the quantity and quality of beans (ibid.). Prolonged wet seasons have been linked to increased fungal diseases (*Phytophthora palmivora*), fruit rot, and a slowdown in the drying process of cocoa beans (Sasmita et al., 2023). Indonesia's cocoa regions may experience a decrease in yield due to a decline in climatically suitable areas (Witjaksono, 2016; Muslimin et al., 2017). Disease-infested pods increase cocoa processing costs, and cocoa production decreased from 400,000 tons in 2012/2013 to 220,000 tons in 2018/2019 (Muslimin et al., 2017; ICCO Statista, 2019). Climate change is causing a 1.80% annual loss in Indonesia's cocoa area from 2003-2022, with young plants dropping at the fastest rate of 6.62% per year. Despite a minor increase in output, Indonesia dropped from fourth to seventh in the world's cocoa production rankings (Sasmita et al., 2023).

3.3.3. Ecuador: Cocoa Nacional/Arriba

The equatorial Pacific's seasonal warming is linked to increased temperatures in cocoa-growing regions (**Table 2**). Due to the country's terrain and equatorial location, the beans have a range of flavours—fruity or nutty (Caselli, 2013). Due to climate change, the global production of fine-flavoured cocoa beans decreased from 320,000 tons in 2015/2016 to 298,000 tons in 2018/2019. Climate change impacts cocoa-growing regions, leading to disease infestations and fungal infestations that affect the quality and flavour of cocoa beans. In 2017, the El-Niño phenomenon influenced the increased incidence of *Monk pest infestations.* The fungus (e.g., *Moniliophthora roreri*) characteristically outbreaks during the rainy season when temperature and humidity conditions are favourable, causing watery cocoa rot. The condition caused the cocoa beans to deteriorate further. Unfavourable rainfall causes pods to rot before they can be harvested. Cocoa trees in other regions restricted pod development due to increased water requirements and high temperatures (Intriago, 2019). Due to the occurrence of the event, cocoa lost its appeal to producers which led to the replacement of cocoa with more profitable crops such as bananas and coffee. Ecuador's position as a top exporter of fine beans was affected by plant disease and the rise of new outstanding cultivars in Africa and Asia (Caselli, 2013). Ecuadorian cocoa exporters require cocoa beans without *monilia roreri* blend, smoke contamination, and 15% humidity. However, a fungus-blend issue arises from unnatural drying in an optimum climate. The situation makes Ecuadorian producers face a significant challenge in adapting cocoa to climate change while meeting high requirements (Jano & Mainville, 2007).

3.4. Explorative Study of Management Practices Applied to Climate Change Mitigation

This study considered the top cocoa certificates that promote sustainable and fair cocoa farming practices. The Rainforest Alliance and Utz, which merged in January 2018, along with Fairtrade, were among the certificates evaluated (Dengerink, 2013; Ingram et al., 2018). Results of this study indicate emissions of greenhouse gases from agricultural activities are a crucial topic in discussions on climate change mitigation (FAOSTAT, 2014). It should be noted that agriculture soil management contributes to greenhouse gases like nitrous oxide, methane, and carbon dioxide, which are primarily produced as by-products of soil transformations in the nitrogen and carbon cycles. Fossil fuel use in agricultural practices, alongside methods that reduce carbon levels and alter soil organic matter, is the primary contributor to greenhouse gas emissions. Rainforest Alliance and Fairtrade advocate for scientific practices to promote energy efficiency and mitigate climate change, focusing on renewable energy and energy-efficient technologies for agriculture.

“Carbon counting” is a critical component of Fairtrade climate standards. Carbon accounting is for the accurate tracking of evaporation and transpiration in agricultural fields. Implementing measures to decrease emissions and prevent significant human intervention in the climate system can potentially stabilize greenhouse gas levels and enable natural ecosystem adaptation (IPCC 2014). Both certificates mandate buffer zones for natural ecosystem preservation and prohibit logging of “virgin forests,” while Rainforest Alliance standards showcase agroforestry management practices for biomass improvement. A well-managed agroforestry system can effectively combat climate change by reducing emissions and sequestering atmospheric carbon (Eagle et al., 2012; Hütz-Adams et al., 2016). The results indicate that the Rainforest Alliance certification promotes tree planting, which can enhance landscape diversity and benefit the environment. Implementing these management practices in specific cocoa-growing regions can yield substantial advantages (**Table 4**). According to Eagle et al. (2012), reforestation is a sustainable method that effectively mitigates the negative effects of deforestation, thereby reducing emissions. Certificates’ standards significantly increased awareness about forest management as a crucial measure to combat climate change, ensuring efficient utilization of forests by adhering to strict ethics. In addition, the standards aim to maximize forest benefits by reducing methane emissions, increasing biomass energy use, and serving as a carbon sink (Gockowski & Sonwa, 2011; Asare & Anders, 2015).

3.5. Explorative Study of Management Practices Applied to Climate Change Adaptation

Climate change impacts cocoa production, necessitating effective management of water, soil resources, shade trees, and pest control to ensure high-quality cocoa (Abdulai et al., 2018a; Abdulai et al., 2018b). The results of this study indicate the conservation practices, crop management, and adaptation techniques required to balance crop needs and minimize system vulnerability and stressors.

3.5.1. Soil and Water Management Practices Applied to Climate Change Adaptation

Climate change impacts on cocoa producers can be mitigated by promoting water conservation and soil management practices, enhancing irrigation efficiency,

Table 4. Energy and GHG emissions reduction practices applied to climate change mitigation.

	Rainforest Alliance	**Fairtrade**
Energy and GHG emissions reduction strategies	Reduce dependency on non-renewable energy sources.	Strengthen local production systems to decrease emissions and increase carbon sinks. Adopt carbon counting to determine the sequestration of greenhouse gases.
	Ensure biomass use does not destruct forest and natural ecosystems.	Adopt production systems that lower dependencies on external input.
	Install energy-efficient processing and drying infrastructure.	
	Utilize energy-efficient cookstoves to increase energy efficiency.	
	Control energy sources associated with transport, production, processing, and domestic use.	
Conservation practices to improve net carbon sequestration and mitigate GHG	Prevent deforestation to maintain natural ecosystems.	Engage farmers on environmental regeneration projects.
	Avoid the destruction of all natural ecosystems since 2014.	Prohibit cutting of virgin forest and prevent deforestation.
	Maintain existing vegetated zones adjacent to ecosystems.	Establish buffer zones to protect natural areas.
	Ensure High Conservation Value areas have not been destroyed (since November 1, 2005).	Prohibit wild species collection.
	Maintain large native trees that pose no hazards to the environment.	Plant agroforestry crops to improve the local environment.
	Restore zones adjacent to aquatic ecosystems.	
	Restore farmed areas of marginal productivity to natural ecosystems.	
	Plant trees to increase availability of biomass energy.	

and promoting sustainable water use in cocoa-growing regions. Timely irrigation, crop rotation, and conservation practices like the use of cover crops and maintaining ground cover can significantly reduce water loss and evapotranspiration rates, ultimately enhancing soil quality in drier regions experiencing severe droughts. The Rainforest Alliance and Fairtrade have similar standards for soil conservation practices. However, the standards of the Rainforest Alliance recommend contour planting. Implementing these practices can enhance agricultural land's net carbon sequestration potential, reduce erosion rates, and improve nitrogen-use efficiency, paving the way for a sustainable transition (FAO, 2009; Braga et al., 2018). The review indicates the Rainforest Alliance has more stringent and precise standards regarding water-use efficiency and soil quality (**Table 5**). The significance of employing system approaches to adaptation and fostering resilient production becomes more pronounced as the severity of climate impacts escalates. It is worth noting that encouraging transformative climate-smart cocoa production is critical for the continuing development of systemic or incremental adaptation (**Figure 2**). Certificates may consider

Table 5. Soil and water management recommendations applied to climate change adaptation.

Rainforest Alliance	Fairtrade
a) Demonstrate reductions in water used for irrigation. b) Document water consumption and establish targets for improving water use efficiency.	Use accessible technology for irrigation to ensure sustainable use of water.
Use groundcovers and mulch to reduce water and wind erosion.	Use groundcover and vegetation to avoid soil erosion.
Use fertilizer to make nutrients available and minimize contamination.	a) Use treated sewage water for fertilizer. b) Match fertilizer use to nutrient needs.
Evaluate future water needs and water availability.	Use water storage facilities in regions with seasonal availability.
Re-vegetate steep areas/adopt terracing to reduce erosion.	Plant ground covers to improve soil fertility and soil structure.
Minimize herbicide use.	Practice intercropping.
Apply compost and mulch to enhance soil health.	Incorporate manure into the soil.
Apply nutrient inputs to crops that compensate for production-related uptake and losses.	Integrate agroforestry.
Adopt crop rotation.	Apply crop rotation.
Plant nitrogen-fixing groundcovers or crops.	
Regularly monitor crop and soil nutrient status.	
Use organic fertilizers when locally available.	
Employ no-till or reduce tillage farming.	
Manage water distribution systems to minimise water waste, erosion, and salinization.	
Identify areas of visual symptoms of nutrient deficiency.	
Minimize nutrient input to crops to prevent eutrophication.	
Apply contour planting/install filter strips to reduce water loss.	

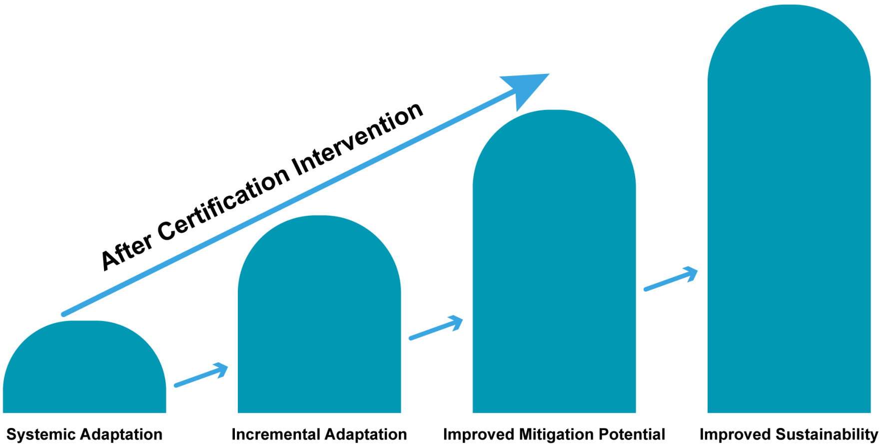

Figure 2. Certification intervention towards sustainable, climate-resilient production. (Source: Author's elaboration).

research or policies prioritizing systemic adaptation such as pest and disease control, improving soil nutrient retention, and shade management. A technology beyond providing shade trees, water management, rapid communication of research, and successful extension can be considered as part of systemic adaptation efforts (Bunn et al., 2019). Considering scaling up efforts for a continuous transformation or incremental adaptation, certificates may consider additional rewards for ecosystem management and making research findings available to farmers (**Figure 2**). This finding is consistent with previous research that observed a positive impact of certification programmes on sustainable cocoa. "The RA certification had a positive impact on producers' income, savings, and cocoa bean production. Cooperatives increased their cocoa quality: measures of flavour, colour, amount of foreign matter, and moisture content have improved across the board. While operations in Ecuador and Indonesia have been halfway successful, there are indications that operations in Ghana have enhanced farmers' practices related to soil and crop fertilization. Other practices include preventing soil erosion, positive changes in forest conditions, and biodiversity over time" (Newsom et al., 2017). "The focus of the Rainforest Alliance and the distribution of environmental requirements within the standard are observable. 'Rainforest Alliance has much broader standards and offers unlimited potential to deal with the environmental problems of the Indonesian cocoa sector'. On the other hand, a definite advantage to introducing Fairtrade certification in Indonesia would be to focus on more social issues but also to strengthen agricultural cooperatives, from which the communities can benefit through development plans" (Jermann, 2016).

3.5.2. Shade Management Practices Applied to Climate Change Adaptation

Shading aids in adaptation by reducing extreme wind, throughfall, and elevated temperature impacts (Köhler et al., 2010; Läderach et al., 2013; Niether et al., 2017b). Certification standards on shade management involve planting trees and establishing vegetation, with minimum tree requirements on farms (**Table 6**). Rainforest Alliance certificate encourages producers to adopt high-shade practices. The certificate supports the allocation of trees for suitable crops to protect biodiversity and reduce disease and pest risks. Farms with adequate shade can safeguard biodiversity and reduce diseases and pests when maintained properly (Schroth et al., 2000; Schroth et al., 2004; Ruf, 2011; Tscharntke et al., 2011; Bunn et al., 2015; Andres et al., 2018). However, in certain cocoa-producing countries, it is still a paradox that some cocoa producers refuse to accept that shading can be advantageous for cocoa growth (Ruf et al., 2015; Andres et al., 2016). Despite the potential issues associated with excessive shading during long dry seasons, it can significantly enhance the chemical composition of cocoa beans (Niether et al., 2017a).

3.5.3. Pest Management Applied to Climate Change Adaptation

Fairtrade and Rainforest Alliance standards acknowledge chemicals affecting bean quality, such as pesticides and herbicides. Chemical classification helps inform technical officers and farmers about their nature and toxicity. Safety standards restrict certain chemicals for environmental promotion, while agrochemical classification by certificates and labels enforces nonconformity (**Table 7**). For example, standards prohibit farmers from combating weeds with herbicides and chemicals under the "Red List". Both certificates establish non-application zones in producing areas to conserve water quality and reduce agrochemical off-site carriage. Additional pest management strategies may focus on crop and tree selection and interaction, as interaction affects insect frequency, with monophagous insects restricted to specific host plants. In contrast, insects with a vast host range (e.g., polyphagous insects) multiply on several host plants (Rathore, 1995; Vos et al., 2003).

Table 6. Shading/Agroforestry recommendations applied to climate change adaptation.

Rainforest Alliance	Fairtrade
a) Farms with shade-tolerant crops must have at least 15% native vegetation coverage across the farm. b) Farms with non-shade-tolerant crops must have at least 10% native vegetation.	Rely on national plan to determine an optimum number of trees to be planted on farms.
Maintain existing agroforestry shade tree cover.	Plant agroforestry crops to improve the local environment.
Adopt border plantings and plant native trees around housing and infrastructure.	

Table 7. Pest management recommendations applied to climate change adaptation.

Rainforest Alliance Pest Management	Fairtrade Pest Management
Adhere to non-application zones around aquatic and wildlife natural ecosystems.	Follow approved spraying buffer zone to protect water resources, air, and humans.
Ensure applied pesticides do not affect active pollinators.	Apply composting, crop rotation, and intercropping aside from pesticide application.

Continued

Ensure pesticides do not expose the natural ecosystem.	Use the least toxic pesticides and prohibit certain pesticides.
Ensure pesticides do not affect crop flowers.	
Establish a vegetative barrier to reduce spray drift.	
Select optimum application techniques and equipment to avoid spray drift.	
Comply with pre-harvest pesticide intervals.	
Integrated Pest Management	**Integrated Pest Management**
Use pest management approaches and adapt to new pest control challenges.	Adopt alternative control (e.g., natural enemies, sticky traps).
Prescribe fire as pest control following an IPM plan (i.e., for fewer impacts on natural ecosystems).	Remove infested plant parts to inhibit the presence of pests and diseases.
Record pest type, infestation dates, degree of damage, and weather during an infestation.	Adopt crop rotation and intercropping to limit pests and disease infestation.
Document significant increases and decreases in pest severity and pesticide use.	Adopt an IPM plan for certified crops and fields, where applicable.

4. Discussion

The discussion of this study addresses knowledge gaps regarding the link between climate and soils, drought and hydrological conditions, sustainable marketing strategies, and effective climate change adaptation and mitigation policies in leading producer countries. Additionally, the study emphasizes the need for sustainable cocoa and the importance of preserving geographical indications (GIs).

4.1. Climate Change Impacts on the Biophysical Conditions of Cocoa

The impact of climate change on sustainable cocoa was examined in this research by evaluating the forecasts in leading cocoa-producing countries. Prior studies primarily focused on the negative impacts of climate change on cocoa-growing regions in top cocoa-producing countries due to elevated temperatures and drought (Läderach et al., 2013; Schroth et al., 2016; Schroth et al., 2017). The uncertainty in future climate projections poses a significant knowledge gap, but climate variability is expected to significantly impact optimal growing conditions in the coming decades (**Table 2**). Studies examined highlight the need for adaptation planning in cocoa-growing regions due to the overall biophysical shift problems associated with climate change. This present research shows that climate change may significantly influence soil chemical properties and nutrient release, which, in turn, harms the organoleptic properties of existing premium cocoa varieties. The metabolic requirements of plant growth enhancers, soil food web stability, and soil fertility are expected to be influenced by the effects of climate change (Hoschitz & Kaufmann, 2004; Nearing et al., 2004; Khursheed, 2016; Thakur et al., 2016; Rumpel, 2019). The predicted inadequate total cation exchange capacity (35%) and soil pH of 5.0 - 7.5 resulting from climate change are expected to lead to soil nutrition problems in producing countries, and the rapidly changing climate may exacerbate the situation (ICCO, 2013). This negative impact will affect the quality of cherelles and pod size that rely on soil nutrients for maturation (ibid). High temperatures cause prolonged water stress, harming cocoa genetic variability and climate change may exacerbate these threats. Elevated temperature affects the lipid content and genotypes of cocoa (Daymond & Hadley, 2005; Daymond & Hadley, 2008; Ayegboyin & Akinrinde, 2016). Climate and edaphic changes in Ecuador are expected to significantly influence the flavour and genotype of cocoa (Sukha & Butler, 2006). Ghana's fluctuating temperatures induce soil fertility heterogeneity, cocoa quality, and yield, with wetland and midland regions having higher organic carbon content than dry areas (Abdulai et al., 2020). The findings of this study indicate that climate variations impact cocoa quality and yield, with Ghana at risk of inhibition of the Theobromine and Flavonoids in its hybrid variety. To address the issue effectively, certificates can promote locally produced liming materials, manure, and organic residues to enhance soil pH and CEC in Ghana and Indonesia (Baah et al., 2011; Kongor et al., 2019). Efficient soil management strategies may optimize water use, conserve organic matter, and improve carbon sink function, contributing to nutrient supply and long-term carbon sequestration due to climate change effects. The knowledge gap in implementing quality response experiments for enhancing soil and water quality in premium cocoa production remains substantial. Ghana's Hybrid cocoa will thrive in specific climate-appropriate regions, while other locations may face challenges like severe drought and temperature-related pests. Increased temperatures and drought in Indonesia threaten the decomposition rate of soil organic matter in cocoa locations. Hydrological conditions and elevated temperatures may cause a shorter dry season, impacting cocoa bean size and potentially affecting fruit tree phenology in Indonesia (Measey, 2010; Witjaksono, 2016). The extreme drought effects in Indonesia cause significant production yield losses ranging from 10% to 46% (Schwendenmann et al., 2010).

4.2. Management Practices for Climate Change Mitigation

Prior studies increasingly recognized agroforestry as a climate change mitigation tool (Eagle et al., 2012; Jacobi et al., 2012; Hütz-Adams et al., 2016). This study indicates that cocoa regions in three producer countries need precautionary mitigation strategies to ensure positive environmental and economic outcomes (**Box 1**). Well-managed agroforestry has the potential to reduce greenhouse gas (GHG) emissions from fossil fuel usage by minimizing the use of organic fertilizer inputs. The findings of this study highlight limited standards for reducing fossil fuel emissions, emphasizing the need for GHG reduction initiatives. Additionally, the findings emphasize the need to categorize emissions from natural sources, supply chains, and land use changes. Explicit standards for efficient manure application and nitrogen fertilizers can reduce methane and nitrous oxide emissions.

Box 1. Biophysical GHG mitigation potential.

Certificates can initiate conservation practices that have the potential to reduce emissions including:

- Improve soil functions: Farming practices to improve carbon sequestration need to be prioritized to positively influence soil functions.
- Reduce methane emissions: Implement standards to check on manure piles and excess application of manure and synthetic fertilizers. The approach has the potential to lower nitrate emissions from large quantities of green manure added to soils (FAOSTAT, 2014).
- Reduce nitrous oxide emissions: Certificates may increase nitrogen use efficiency. Nitrogen fertilizers when used appropriately, can minimize nitrous oxide emissions (Eagle et al., 2012).
- Promote energy efficiency: Farmers may consider using more renewable energy and efficient power sources. Biomass, wind, and solar installations on farms can contribute to reduced energy losses.
- Reforestation: Consider the forest serves as a carbon sink source and encourage the growing of trees off-farm and promote "Fertiliser for Forest" for a net positive impact (Gockowski & Sonwa, 2011).
- Deforestation and agricultural land burning contribute to high GHG emissions in the West African belt. The increase in cocoa production in the West African belt is attributed to agricultural expansion into the forest areas (Whoriskey, 2019; Fountain & Hütz-Adams, 2022; Mighty Earth, 2022). Certificates may design and implement land use emissions reduction initiatives in cocoa regions in West Africa.
- Standards of certificates must continually acknowledge tree-associated plants as key indicators of agricultural sustainability, potentially incentivizing cocoa producers to invest in tree planting to enhance carbon sinks in cocoa-growing regions (Braga et al., 2018; Sonwa et al., 2018).
- Organic farming, biotechnology, and other agricultural innovations can help to reduce greenhouse gas emissions. Increased production efficiency increases total yield without increasing land use, potentially lowering GHG emissions per unit of production (Eagle et al., 2012).

4.3. Management Practices for Climate Change Adaptation

Cocoa genotypes that are resistant to heat stress and have efficient water use traits may be recognized and utilized (Abdulai et al., 2018a). Planting shade trees can be an effective measure to safeguard cocoa plants from elevated temperatures and enhance soil functionality (Braga et al., 2018). Shading is a viable alternative to minimize the susceptibility of cocoa to heat stress and improve soil function. Due to elevated temperatures, the buffering capacity of shade trees against drought can benefit arid areas of producer countries (**Box 2**). The findings of this research are consistent with previous studies that showed Rainforest Alliance has a high-shade measure necessary for climate change adaptation (Ellis & Keane, 2008; Gockowski et al., 2013; Jermann, 2016). In Ghana and Indonesia, the optimum use of shade trees to protect cocoa from elevated temperatures seems to be the optimum conservation practice (Anim-Kwapong & Frimpong, 2006; Köhler, et al., 2010; Tscharntke et al., 2011; Ruf et al., 2015; Schroth et al., 2017). Projections of high precipitation in Indonesia and Ecuador may require shade trees to reduce throughfall to protect cocoa from heavy raindrops (Niether et al., 2018). Promoting technical efficiency and robust innovation systems are the best strat-egies for producers' resilience to drought in Indonesia (Keil et al., 2008; Schwendenmann et al., 2010). Moreover, soil management practices, such as improving nitrogen-use efficiency and preventing erosion, can enhance soil fertility and water-use efficiency in cocoa farms. Considering incremental adaptation efforts, certificates may consider introducing an ideal amount of the most nutrient-efficient shade tree species to increase biomass (Oelmann et al., 2010). Future research would be critical to determine whether shading and shade density standards compromise shade thresholds in certain cocoa-growing regions. The growth of pests and diseases caused by dry-wet cycles threatens cocoa (Schroth et al., 2000; Anim-Kwapong & Frimpong, 2006). It is worth mentioning that some fungicides and pesticides can significantly reduce cocoa yield and quality in dry periods (Abdulai et al., 2018a). Due to the threats of climate change, certificates may focus on developing location-specific adaptive measures to increase the resilience of production systems to disease and pest risks. Additionally, certificates may focus on well-designed integrated pest management (IPM) to minimize interference in cocoa ecosystems (Vos et al., 2003).

Box 2. Adaptation strategies.

Certificates can initiate climate change adaptation policies including:

- Inconsistent rainfall patterns and temperature stress in identified cocoa-producing regions affect less drought-tolerant varieties. Certificates can help initiate adaptation standards that focus on developing drought-tolerant cocoa varieties, especially in places with relatively low genetic diversity (Läderach et al., 2013).
- Hydrological cycle changes could impact all three countries, and certificates may promote shade trees with low water consumption strategies to significantly protect cocoa.
- Certificates can also promote the efficient use of fertilizer to contribute to rigorous nutrient cycles and soil quality. By focusing on the appropriate use of mineral-based fertilizers, soil quality could be influenced positively.
- Irrigation is traditionally used in cocoa production systems. However, an irrigation infrastructure could be crucial in cocoa production systems to offset the effects of evapotranspiration, especially in high-temperature or severe drought regions (Anim-Kwapong & Frimpong, 2006). Sustainable irrigation systems can reduce leaching losses, and standards that focus on increasing water-use efficiency and improving irrigation management can incentivize cocoa quality improvement.
- In Indonesia and Ecuador, cocoa is grown in locations near islands or oceans. Therefore, optimal hydrological-meteorological and communication networks can improve cocoa production. Certificates can educate producers to understand hydrological dynamics in cocoa production to reduce the impacts of El Niño, flood, La Niña, or sewage disposal. Moreover, certificates can institutionalize farmers' access to ENSO forecasts to reduce drought-related productivity issues and cocoa mortality (Keil et al., 2008).
- Uncertainty in climate projections requires drought management policies that emphasize good communication on climate, pesticide science, and infrastructure (ICCO, 2010). Information on rainfall and temperature variability in cocoa-growing regions can assuage climate change uncertainty and aid producers in managing droughts for crop productivity.

4.4. Sustainable Marketing and Geographical Indications

The agronomic practices and edaphic conditions required for attaining "territory-based geographical indications or place-based intellectual property" can be influenced by projected drought or excessive heat in producer countries (Clark & Kerr, 2017). The findings of this study provide valuable insights into the potential challenges that cocoa-producing countries may face in maintaining the distinct flavours and characteristics of their cocoa amidst changing climatic conditions. This present study posits that, just like wine, chocolate reflects the environment where the bean is produced, dried, and fermented (Caselli, 2013). The anticipated rise in climatic differences between wet and dry regions will significantly limit geographical quality. The condition suggests a potential decrease in the organoleptic quality of existing cocoa varieties, potentially leading to countries with favourable climates gradually dominating the cocoa market. The concern brings attention to two significant biophysical impacts of climate change. On the one hand, the challenges in quality cocoa production are expected to cause a shift in production areas, creating both opportunities and threats within and between countries (Schroth et al., 2016). On the other hand, producing high-quality cocoa in certain producer countries may cease unless more drought or heat-tolerant varieties are developed. In an extreme situation, progressive crop change is the most likely climate-resilient strategy to protect geographical indications (GIs) in producer countries (Schroth et al., 2016; Schroth et al., 2017). However, a longer planning horizon is required for crop change and the adoption of modern science-based methods to improve conditions (ibid). These proposed methods appear to be unachievable mechanisms for maintaining the credence attributes of products or GIs. Despite these critical issues, future bioclimatic suitability in producer countries could lead to a more even distribution of cocoa production, depending on available adaptation mechanisms. Certificates may partition agricultural lands in producer countries to implement standards, encouraging the zoning of cocoa-growing regions for investment in adaptation plans within specific zones. Zoning can sustainably increase cocoa production in areas less susceptible to climate change, compensating gains in one location for losses in other cocoa-growing regions (Schroth et al., 2017). Because spatial changes in agroclimatic zones allow agroecological zoning, a probable expansion could benefit less shade-tolerant varieties. In addition, an expansion approach will allow homologous climate zones to adapt to cocoa management strategies (Bunn et al., 2015). These effective agronomic strategies can help maintain the cost and quality of trademarks without altering production processes.

In another potential scenario, certificates and producer countries may explore redistribution and substitution options to enhance cocoa cultivation in response to future climatic conditions (Blois et al., 2013). For instance, in the coming years, the predicted higher rainfall and temperatures for Ghana and Ecuador may suit a variety from Indonesia (above 30˚C projected). Varietal substitution would promote sustainability by replacing less productive varieties with suitable ones. The substitution strategy is not for achieving sustainability only but has the potential to compensate for losses in certain countries by replacing less productive cocoa varieties with more productive ones.

Certification assistance programmes that prioritize Environmental, Social, and Governance (ESG) aspects, along with sustainable practices, to safeguard the credence attributes of products and emphasize product differentiation can reduce the risk of producer countries losing geographical indications (GIs) or place-based intellectual property. Producer countries must effectively engage with the growing importance of ESG, allowing growers a pathway to environmental, social, and governance certification. To preserve the quality trademarks of cocoa without changing production processes, producer countries may prioritize viable adaptation and marketing standards for GIs. Because the connection between a commodity and its original place of production makes GIs achievable, efficient preservation of production processes and cocoa quality attributes is necessary to adapt geographical indications (De Beer et al., 2014; World Intellectual Property Organisation, 2016; Clark & Kerr, 2017).

4.5. Limitation of Study

This study examined the impacts of climate change on the biophysical environment of cocoa and the adaptation and mitigation potential of cocoa certificates. However, there are several limitations regarding analyses on standards of certificates that should be considered when interpreting these analyses. The scope of this research was restricted to environmental standards while looking for climate-related standards. Furthermore, the eligibility criteria for determining suitable articles for this research did not allow for the inclusion of complete texts written in Spanish or French. As such, there are limited facts considering expected climate impacts on cocoa and the actual role of certificates in non-English speaking producer countries (e.g., Ivory Coast). The situation may explain why few English studies were available for a case study on Ecuador, considering the topic.

5. Conclusion and Future Explorations

The findings show that climate change poses a significant threat to premium cocoa production and that certificates and labels are pivotal in promoting sustainable practices for addressing climate change-related issues. Prior studies indicated suitable climatic conditions in specific producer countries today would increasingly become less suitable for cocoa production in the coming years. This present study explored how the impact of climate change could alter quality definitions of cocoa and highlighted the role of certificates in prioritizing adaptation and mitigation standards in producer countries. In addition, the study highlighted the importance of sustainable cocoa sourcing for maintaining perceived GIs. This study underscored that future biophysical conditions and local climates may differ from present conditions, and cocoa production may occur in areas of low suitability. A feasible scenario would require producer countries to shift production areas or adopt drought-resistant genotypes due to the spatially differentiated pattern of climate impacts. It is worth noting that climate change would influence soil, hydrological, and pest conditions in cocoa-growing regions, which may force the identified countries to reduce or cease production. Thus, for climate adaptation, a focus should be on essential standards that ensure specialization in available technologies for soil quality, water use efficiency, and efficient pest management practices. The Rainforest Alliance and Fairtrade recommend climate-smart or adaptation strategies for premium cocoa production. These include agroforestry, improved water management, soil conservation, and reduced chemical inputs. Incentivizing climate-smart agriculture and promoting biodiversity conservation could be pathways for climate change resilience and sustainable cocoa. Certificates can promote essential soil and crop management practices that mitigate climate threats to cocoa. Another important recommendation is the optimal use of shade to enhance microclimates. This measure will ensure the productive use of soil water and nutrients for net positive results in regions with extreme heat. The findings show that certificates and labels often include standards that promote biodiversity protection. Preserving diverse biodiversity and ecosystems enhances cocoa farmers' capacity to cope with climate-induced challenges. Due to the observed biophysical impacts, certificates can help reduce uncertainty about climate change scenarios by developing a hydrological-meteorological network. This approach can support early adaptation strategies to forestall the worsening impacts of climate change in producer countries, such as an increase in sea levels and the La Niña effect. The spatially differentiated patterns of climate impact imply that certificates focus on relocating and re-zoning arable lands within and between producer countries for sustainable intensification and expansion. This approach compensates for losses in cocoa-growing regions with gains in certain areas. To maintain perceived Geographical Indications (GIs), major producer countries must apply sustainable practices to return credence qualities to the pre-climate change period.

Climate change mitigation efforts by certificates should focus on modern methods to continuously minimize methane and nitrous emissions, conserve ecosystems, and promote zero deforestation commitment. Certificates and labels may encourage off-farm tree growth practices and the restoration of natural ecosystems. Standards of certificates and labels that focus on reducing the carbon footprint of cocoa production recommend farmers sequester carbon in soils through tree planting, afforestation, forest preservation, and energy-efficient production methods. Well-managed shade trees reduce soil evaporation, buffer climate variability, sequester carbon, and mitigate greenhouse gas emissions, contributing to climate change mitigation efforts. Conservation methods such as energy efficiency, nitrogen-use efficiency, yield improvement technologies, and agroforestry can significantly decrease GHG emissions in agricultural lands. To this end, this present study recommends:

- The link of research and extension in cocoa-producing countries.
- Promotion of strategies that support knowledge and understanding of shifting biophysical conditions in cocoa-producing countries.
- Location-specific standards are prioritized for more intensive adaptation and mitigation practices in producer countries.

- Focused studies to explore the potential effect of climate change on biophysical conditions at finer geographic scales.
- Climate policies and certification standards that consider, discuss, and modify adaptation and mitigation strategies to restore cocoa quality to the pre-climate change periods.

Data Availability Statement

All data on standards of certificates used in this study is publicly accessible documents of Fairtrade and Rainforest Alliance certificates. All articles used in the systematic review are duly referenced.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Appendix: PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	1-2
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	2-4
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	5
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	5-6
Search strategy	7	Present the full search strategies for all databases, registers, and websites, including any filters and limits used.	6-7
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	5-7
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	5-7
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	5-6
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	5-6
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	NO
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	NO
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	5-7

Continued

	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	6
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	NO
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	NO
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	NO
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	NO
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	NO
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	8-9
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	8
Study characteristics	17	Cite each included study and present its characteristics.	8-9
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	NO
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	NO
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	NO
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	NO
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NO
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NO
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	NO
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	NO
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	19-26

Continued

	23b	Discuss any limitations of the evidence included in the review.	27
	23c	Discuss any limitations of the review processes used.	27
	23d	Discuss implications of the results for practice, policy, and future research.	20-27
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	NO
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	NO
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NO
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	YES
Competing interests	26	Declare any competing interests of review authors.	YES
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	YES

Supplementary Materials

The supporting information and data can be downloaded at: Fairtrade standards at: https://files.fairtrade.net/standards/Climate-Standard_EN.pdf;
https://files.fairtrade.net/standards/HL_EN.pdf;
https://files.fairtrade.net/standards/SPO_EN.pdf.
Rainforest Alliance standards at:
https://www.rainforest-alliance.org/resource-item/2020-sustainable-agriculture-standard-farm-requirements/;
https://www.rainforest-alliance.org/press-releases/2017-san-standard-released/.
All other publications cited are dully referenced.