IMPACT OF POLLINATOR TECHNOLOGY ADOPTION ON COCOA PRODUCTIVITY IN THE OSINO COCOA DISTRICT IN THE EASTERN REGION, GHANA

BY

JOSEPH GYIMAH BOAMPONG

(11007912)

THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE (MPHIL) IN AGRIBUSINESS

DEPARTMENT OF AGRICULTURAL ECONOMICS AND AGRIBUSINESS

SCHOOL OF AGRICULTURE

COLLEGE OF BASIC AND APPLIED SCIENCES

UNIVERSITY OF GHANA, LEGON

NOVEMBER, 2024

DECLARATION

I, Joseph Gyimah Boampong, the author of this thesis titled **"IMPACT OF POLLINATOR TECHNOLOGY ADOPTION ON COCOA PRODUCTIVITY IN THE OSINO COCOA DISTRICT IN THE EASTERN REGION, GHANA"** do hereby declare that with the exception of the relevant references duly cited, this thesis was entirely done by me at the Department of Agricultural Economics and Agribusiness, University of Ghana, Legon from November, 2023 to March, 2025. This work has not been presented either in whole or in part for any other degree in this University or elsewhere.

.... 14-11-2025

Joseph Gyimah Boampong Date

(Student)

.... 14/11/2025

Dr. John Baptist Donsaananang Jatoe Date

(Major Supervisor)

.... 14.11.2025

Dr. Charles Yaw Okyere Date

(Co-Supervisor)

DEDICATION

I dedicate this work to my parents WO II Samuel Kwame Gyimah and Mrs. Georgina Akosua Nsiah Gyimah, my wife Mrs. Rachel Arhin Gyimah, my children, Lady and Jenelle. This work is also dedicated to my siblings for their support and encouragement throughout the period of my study.

ACKNOWLEDGMENT

My greatest acknowledgement is to God Almighty for His guidance and protection throughout the years. I express my sincere gratitude to my supervisors, Dr. John Baptist Donsaananang Jatoe and Dr. Charles Yaw Okyere for their support and guidance. I am also grateful to Senior Members and the staff at the Department of Agricultural Economics and Agribusiness for their support. I would also like to express my gratitude to my course mates especially Gilbert Addae, Jerry Akanwake, Ambrose Adama and Sena Atsutse for their support.

My sincere appreciation also goes to all respondents and enumerators for sacrificing their time and efforts to assist me get relevant information for this study.

Finally, am thankful to all friends and loved ones for endless encouragement and to all those that have contributed in one way or the other to the success of this work, am so grateful.

ABSTRACT

Improving pollination in cocoa production is important to enhancing yields in Ghana. However, the decline of natural pollinators (midges) in cocoa has been identified by Ghana Cocoa Board as a major challenge to increasing cocoa production. Interestingly, the adoption of improved agricultural technologies such as pollinator technology, which increases the population of midges, is an important component in cocoa productivity. This study examines the impact of pollinator technology adoption on cocoa productivity in the Osino cocoa district of Ghana using primary data from 400 cocoa farmers. The study employed descriptive statistics in assessing the perception of cocoa farmers on pollinator technology. The binary logit model was used to determine the factors that influence the adoption of pollinator technology. The Inverse Probability Weighted Regression Adjustment (IPWRA) was used to analyze the impact of adopting pollinator technology on productivity in the study area, and finally, the Kendell's coefficient of concordance was employed to identify and rank the constraints to pollinator technology adoption. The study revealed that 47.5% of cocoa farmers have adopted pollinator technology and they have positive perceptions about the benefits of adopting the technology, such as increase in yields and improved soil quality. The socio-economic factors influencing farmers' decision to adopt pollinator technology were access to extension services, training, membership of farmer-based organization and access to credit facilities. The findings showed that adopters of pollinator technology have average yield enhancement of 421.70 kilogram per hectare (kg/ha). The key constraints identified from the study were inadequate information, technical knowledge gaps, and lack of training which limit the rate of adoption. It is recommended that COCOBOD offers education, training, and support to cocoa farmers on pollinator technology. This will enhance its adoption for increased cocoa productivity, improve farmers' livelihoods, and contribute to environmental protection.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Cocoa is an important cash crop to the economies of producing countries and livelihood of smallholder farmers globally. Ghana is the second largest producer of cocoa globally. The cocoa sector in Ghana contributes about 20% to global cocoa production (International Cocoa Organization (ICO), 2017). The cocoa sector is a major source of income for smallholder farmers and an important aspect of the economy of Ghana. It contributes to foreign exchange, employment, food security, livelihoods and national development (Maguire-Rajpaul et al., 2020). According to Amponsah-Doku et al. (2022), the cocoa sector in Ghana supports the livelihoods of about 30 percent of Ghanaian farmers. However, it has been reported that production of cocoa in Ghana has been modest over the years with only 30% of the potential yield been produced (Aneani & Ofori-Frimpong, 2013). Smallholder farms dominate cocoa production in Ghana, ranging from one hectare to three hectares, with most farmers using traditional methods that limit productivity (FAOSTAT, 2020).

The cocoa sector in Ghana has a potential to increase yields through the adoption of modern practices. Adoption of improved agricultural technologies is an important component in cocoa productivity. Kumar et al. (2020) argued that improvement in agricultural productivity can only be realized through the adoption of improved agricultural technologies, especially in developing countries. Improvement in cocoa productivity is important to increasing yields for improved income and livelihood of the smallholder farmers. In addition, increase in yields will mitigate deforestation due to land clearing for cocoa productions which have deleterious effect on the environment (Adebayo et al., 2022).

While the average yield modest at around 400-500 kg/ha, expected yields could be between 800-1,000 kg/ha (Lambert, 2014; Donovan et al., 2016; Bymolt et al., 2018) with the potential to achieve 1,500-2,000 kg/ha (Aneani et al., 2013). This low yield has resulted in a yield gap between the expected yield and potential yield. The trend of low yield in cocoa production has been attributed to increasing climate variability, illegal mining, pests, diseases, habitat expansion, land degradation, inappropriate use of agro-chemicals, and poor natural pollination services (Ali and Danso-Abbeam 2018; Gassner et al. 2019; Weiner 2017). Additional factors such as poor phytosanitary practices, lack of improved varieties, and low soil fertility, were found as contributing factors to the cocoa yield gap (Aneani and Ofori-Frimpong, 2013). However, inadequate pollination has emerged as a significant issue to yield decline as observed by Winder (1977) who noted a decline in pollination during the dry season due to reduced midge populations.

With increasing demand for cocoa globally, COCOBD has promoted various technical changes with interventions such as cocoa rehabilitation, distribution of hybrid seedlings, subsidized fertilizers, mass spraying, farmer education on best agronomic practices and hand pollination (Jebuni-Dotsey et al., 2023) to improve yields/productivity. However, despite the interventions to improve cocoa production productivity remains low and below the expected production. Toledo-Hernandez et al., (2020) noted these sustainability interventions are necessary but not sufficient to close the yield gap especially when less than 10% of cocoa flower get pollinated under natural conditions. According to Claus et al. (2018) though intensification of such interventions and input use may be necessary to maintain and increase cocoa output, gains in productivity is enhanced by facilitating pollination intensity on the cocoa farm.

Pollination is essential in increasing cocoa production due to its important role in cocoa pods formation. Toledo-Hernandez et al., (2017) averred that improving productivity in cocoa is highly dependent on effective pollination of cocoa flowers which is supported by insect pollinators. Cocoa pollination is mainly by *ceratopogonid midges* of the genus *Forcipomyia* (Chaudhary & Chand, 2017; Winder, 1977). Pollination services are important in increasing sustainable cocoa production in agriculture (Knapp et al., 2017; Kovács-Hostyánszki et al., 2017). Studies have shown that for sustainable cocoa production, the use of pollination services through the propagation and preservation of natural pollinators is important for addressing the issues of low yields (Lippert et al., 2021; Vanhove et al., 2020; Claus et al., 2018; Frimpong et al., 2009). Sustainable cocoa production involves maintaining the productivity of the land and improving cocoa yields, with minimal or no damage to the natural resources (Pretty & Bharucha, 2014). Tolera and Ballantyne (2020) postulates that sustainable cocoa production should involve the best use of agricultural technologies in habitat management practices such as pollinator technology (breeding substrate) for crop improvement. The pollinator technology approach involves the breeding and preservation of midges using decomposing cocoa leaf litters, cocoa pods husks and slices of banana pseudo stem to increase pods sets on the cocoa tree (Tolera & Ballantyne, 2020). However, the decline of midge pollinators on cocoa farms is a potential risk to Ghana's cocoa production (Addae et al., 2024). The low population of midges on cocoa farms could be attributed to the removal of suitable habitats associated with intensification of cocoa production, deforestation, and illegal mining.

According to Ramos-Jiliberto (2020), there is increasing interest in developing and promoting pollinator technology through cocoa breeding techniques to enhance crop yield by enhancing natural pollination processes. Groeneveld et al. (2010) postulates that despite an increase of fruits abortion with pollination intensity yield in cocoa is determined by the number of flowers pollinated. This indicates that pollination deficit in cocoa can be high and a better knowledge of pollination services to devise adequate management practices may be essential for increasing production. To address the yield gap observed in cocoa production (Asant et al., 2022), there is the need to assess the adoption of productivity enhancing technology such as the pollinator technology among cocoa farmers and investigate its impact on cocoa productivity in Ghana.

1.2 Problem statement

Cocoa production is an important economic drive to national development. However, Ghana's cocoa production has reported low yields despite intensification in the use of agricultural inputs and interventions (Jebuni-Dotsey et al., 2023). The intensification of inputs such as fertilizers may maintain cocoa output, but productivity gain is enhanced by facilitating the services of natural (midge) pollinators through effective pollination on the cocoa farm (Elisante et al., 2019; Claus et al., 2018). Pollination rates in cocoa are low and inconsistent on cocoa farms despite increasing evidence that improving pollination on the cocoa farm can improve yields (Jebuni-Dotsey et al., 2023). In addition, it is reported that decline in pollinators have dire consequences on livelihood of small-scale farmers due to low yields in cocoa production (Sawe et al., 2020; Rhodes, 2018).

It is estimated that about 79-90 percent of flowers that detached from the cocoa trees are attributed to lack or insufficient pollination which results in low pod sets (Wongnaa et al. 2021; Castro Muñoz et al., 2017). The declined pollination services by midge (*forcipomyia spp*) have been identified by Cocobod as a major challenge to increasing cocoa production, for which reason the artificial hand pollination programme was introduced in 2016/2017 crop year (Jebuni-Dotsey et al., 2023). Despite evidence that hand pollination increases yields (Ameyaw, 2023), its impact is significantly determined by the cost of labour (expensive), age of farmer, the requisite skills and the risk of child labour as a rife in cocoa farms in major producing nations like Côte d'Ivoire and Ghana (Asante et al., 2023).

Given the potential negative effect of natural pollinators decline on cocoa farms, it is important to implement pollinator management practices and good environmental measures to improve productivity. However, limited attention has been directed towards cocoa farmers to adopt pollinator technology to enhance effective pollination on their cocoa farms (Hevia et al., 2021). According to Kleijn et al. (2015), while the decline in yields due to inadequate pollination services is a key research concern and policy focus in the US and Europe, there is comparatively limited research and policy focus in developing countries like Ghana (Fijen et al., 2020; Aizen et al., 2019). Despite the potential of cocoa pollinator technology to increase cocoa yields (Wanger et al., 2021), farmers' perceptions on its adoption remain largely unexplored. The success of any agricultural technology is highly dependent on the adoption by the farmers. The adoption and impact of such agricultural technology could be attributed to several factors, such as lack of awareness, perceived costs, traditional practices, and risk aversion (Rogers, 2003).

Furthermore, government policies, access to agricultural extension services, and resource availability are critical in shaping farmers perception and their decisions on adoption and its impact on improved or new agricultural technologies (Adjei-Nsiah & Klerkx, 2016). Earlier studies by Frimpong et al., (2009), suggested that breeding substrate technique improves the habitat and efficiency of natural pollinators. However, there is the need for more empirical data on its effect on cocoa productivity. In addition, studies on pollinator technology adoption and its impact are limited in literature. Potts et al. (2016) and Klein et al. (2007) posits that while existing literature emphasizes the potential benefits of pollinator technology in increasing cocoa productivity, its practical adoption and application could be limited by constraints such as inadequate information and technical knowledge to the farmer. Thus, there is the need to identify the constraints to the widespread adoption of pollinator technology among cocoa farmers in Ghana.

Previous studies on breeding techniques for cocoa pollinators used field experimental plot design and mainly focused on the most suitable and preferred substrate in breeding of the midges (Toledo-Hernández et al., 2021; Frimpong-Anin and Kwapong, 2020; Suganthy, 2019; Adjaloo et al., 2017; Young, 1982), enhancement and enrichment of breeding cocoa pollinators (Saripah & Alias, 2018; Saripah, 2013), and impact of insecticides on pollinator enhancing substrate (Vanhove et al., 2020). Other related studies on pollinator technology focused on artificial hand pollination (Asirifi et al., 2024; Wongnaa et al. 2021; Wurz & Tscharntke, 2021). The pollinator assemblage in cocoa production and the relative impact of pollinator technology is less researched in Ghana (Addae et al., 2024; Frimpong et al., 2011). Research on cocoa insect pollinators, especially in Indonesia and Colombia, has been widely studied (Jaramillo et al., 2024; Zakariyya et al., 2016). Lander et al. (2025) highlighted that increasing leaf litter, planting cacao trees more densely, using taller shade trees, and reducing agrochemical use boost pollinator populations and pollination rates, leading to higher pod yields, and also provide additional ecological benefits, such as improved soil moisture, fertility, and temperature regulation. Their findings revealed that natural pollination rates using leaf litters were highest in Ghana (27.1%), compared to Brazil (12.2%) and Indonesia (11.1%), suggesting that pollinators in Ghana are both more abundant and more efficient. There is paucity of relevant literature on the factors that influence the adoption of pollinator technology among cocoa farmers and the impact adoption has on cocoa productivity in Ghana. This study examines the adoption and the impact of pollinator technology on productivity among cocoa farmers in the Osino cocoa district in the Eastern region of Ghana.

1.3 Research questions

The study seeks to address the following research questions;

1. What are the perceptions of cocoa farmers on the adoption of pollinator technology in the Osino cocoa district?
2. What are the factors influencing the adoption of pollinator technology among cocoa farmers in the Osino cocoa district?
3. What are the effects of pollinator technology on cocoa productivity in the Osino cocoa district?
4. What are the constraints to adoption of pollinator technology among cocoa farmers in the Osino cocoa district?

1.4 Objective of the study

The main objective of the study is to assess the impact of pollinator technology adoption on cocoa productivity in the Osino cocoa district in the Eastern region of Ghana. The specific objectives are:

1. To examine the perception of cocoa farmers on pollinator technology in the Osino cocoa district

2. To identify the factors influencing the adoption of pollinator technology among cocoa farmers in the Osino cocoa district
3. To estimate the impact of pollinator technology on cocoa productivity among cocoa farmers in the Osino cocoa district
4. To identify and rank the constraints to the adoption of pollinator technology among cocoa farmers in the Osino cocoa district.

1.5 Justification of the study

The current study contributes to the literature on pollinator technology (breeding substrates techniques) by adding to the existing knowledge on the technology with information on the impact of pollinator technology on productivity in Ghana. This will help COCOBOD and other stakeholders in the cocoa sector know the perception of cocoa farmer about the technology, and develop appropriate policies and training/educational programmes on pollinator technology.

The findings of this study will influence farmer's action towards the adoption of pollinator technology within the cocoa sector. It is expected that the results from this study could help form a good basis for effective breeding of the midges to enhance cocoa productivity and improve the income of cocoa farmers. In addition, it will help promote sustainable climate resilience and environmental-friendly cocoa production through the use of organic materials in breeding of the pollinator insects (midges). Understanding the cluster information on perception and factors influencing farmers' decision will enable the development of strategies to facilitate the adoption of this pollinator technology among cocoa farmers. The outcome from the study would enhance research and development of the pollinator technology by the Cocoa Research Institute of Ghana (CRIG) and provide appropriate information for COCOBOD. This will be used to intensify awareness creation through community extension officers to the cocoa farmers. Finally, this study will contribute to academic literature and serve as a source of reference for future studies on similar topics in Ghana and elsewhere.

1.6 Organization of the study

This study is been organized into five (5) chapters. Chapter two presents review of literatures relevant to the study including the concept of pollinator technology and its adoption, and empirical reviews. Chapter three discusses the research methods that were used in this study including the sources of data, sampling and sample size determination, and a brief description of the study area. Chapter four presents the results and the discussion of the results. The summary of the findings, conclusions and recommendations of the study are presented in Chapter five.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of relevant literature for the study. It covers an overview of Ghana's cocoa sector, pollinator technology (breeding substrate) and the adoption of agriculture technologies.

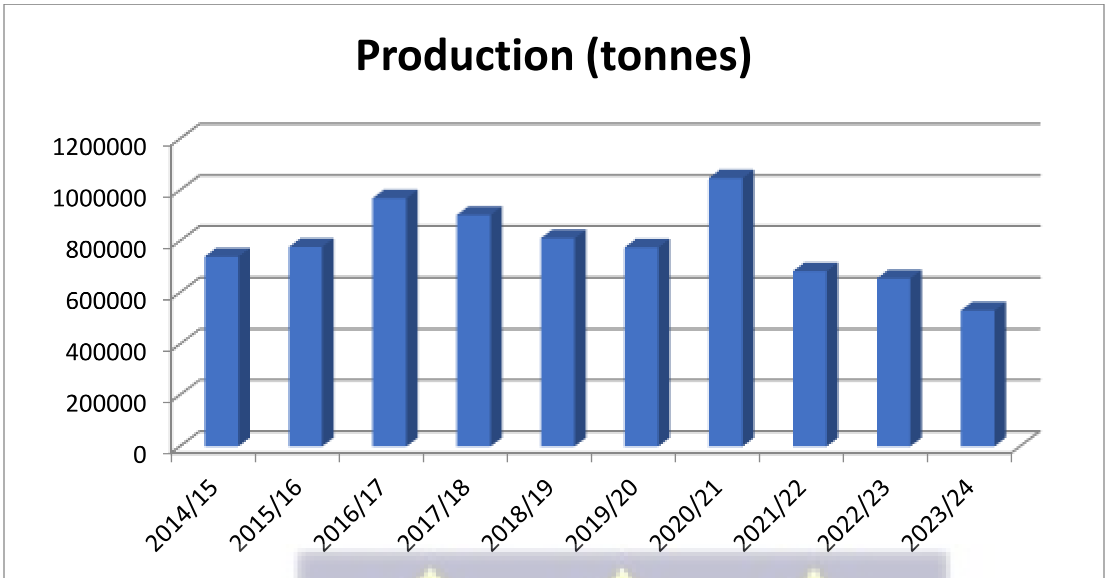
2.2 Overview of Ghana's cocoa sector

Cocoa production contributes to Ghana's economy significantly as Ghana is ranked the second largest cocoa producer and exporter in the world (FAO, 2018; Fountain & Hütz-Adams, 2018). The cocoa sector plays an important role in national economic development and the well-being of the population. The sector contributes to the country's gross domestic product and foreign earnings. It also creates employment and is a source of livelihood for many Ghanaians (Schulte et al., 2020; Asamoah et al., 2018). According to Roth et al. (2017) productivity in Ghana's cocoa sector remains relatively low with an average yield of 400-500 kg per hectare, compared to potential yields of 1,000 kg per hectare. This low productivity is caused by factors such as aging cocoa trees, improper farm management practices, low soil fertility, poor shade management and limited access to inputs like fertilizers and pesticides (Baah, 2020).

Ghana's cocoa sector has focused on short-term production goals (O'Sullivan et al, 2021), often neglecting environmental sustainability, the well-being of cocoa farmers and long-term viability of the sector (Tropenbos International-Ghana (TIG), 2018). However, recent initiatives have focused on promoting sustainability through programmes designed to promote sustainable farming that aim to promote sustainable farm practices, reduce deforestation, and enhance farmers' livelihood (Asare et al., 2018). Additionally, the adoption of climate-smart agriculture practices, such as agroforestry in cocoa production, is gaining traction as a way to enhance resilience to climate change (Riyadh et al., 2021; Schroth et al., 2016).

Ghana's cocoa sector over the last decade reflects a period of relative growth and record output culminating in the 2020/21 season, followed by a sharp contraction driven by disease, aging trees, land-use competition, climate variability, and market distortions. From 2015 to 2017, Ghana experienced moderate growth in production. Annual output rose from about 740,000 tonnes in 2014/15 to nearly 967,000 tonnes in 2016/17. During this period, average yields improved to approximately 0.7 tonnes per hectare, higher than the long-term average of 0.45 tonnes per hectare (FAO, 2023). Production declined to approximately 904,000 tonnes in 2017/18 and 811,000 tonnes in 2018/19, largely due to inconsistent rainfall patterns, pest and disease pressures, and the aging of cocoa tree stock (Cocobod, 2023). In 2019/20, production declined further to about 775,000 tonnes, with yield estimates also declining. A landmark occurred in the 2020/21 season when Ghana recorded its highest ever crop of approximately 1.05 million tonnes (Statista, 2023). Yields increased above 0.8 tonnes per hectare, highlighting the potential for improved productivity under conducive conditions. Ghana's cocoa production since the 2020/2021 record setting season, has registered three consecutive seasons of decline 683,269 metric tonnes in 2021/2022, 655,808 metric tonne in 2022/2023 and 530,873 metric tonnes in 2023/2024 (ICCO, 2022, 2023, 2024).

Figure 2.1: Ghana's Cocoa Production (2014/2015 – 2023/2024)



Source: Cocobod annual report (2014/2015-2020/2021); ICCO, (2022-2025)

2.3 Factors affecting cocoa production in Ghana

Ghana is a significant global player in cocoa production, not only due to its worldwide importance but also because of the foreign exchange earnings it generates. Despite steady production trends, there are notable inconsistencies. According to Dormon et al. (2004), these inconsistencies stem from various factors, with drought being the primary cause of reduced cocoa output. This perspective is corroborated by Schneider et al. (2023) who emphasized that extended droughts in the 1980s greatly affected production. They reported that 30–40% of cocoa farms in the Volta, Ashanti, and Brong Ahafo regions experienced declines during this period. Additionally, Dormon et al. (2004) identified aging cocoa trees as another contributing factor to reduced yields.

To better understand the reasons for low cocoa production, numerous researchers have utilized statistical methods and modeling approaches. Uwagboe and Agbongiarhuoyi (2020), for instance, investigated the impact of pests and diseases. Using socio-economic data, systematic sampling, and integrated pest management (IPM) techniques, they collected information from respondents via structured questionnaires. Their analysis, presented in graphs and evaluated using chi-square, revealed that a majority (60) of the surveyed farmers were educated males. Moreover, 75% of respondents employed IPM practices, which correlated with higher cocoa yields.

Similarly, Dormon et al. (2004) conducted a diagnostic study to explore farmers' perspectives on low production. Focusing on three towns in the Suhum-Kraboa Coaltar district, they employed an action research methodology and analyzed results qualitatively. Their findings pointed to two main causes of low productivity: biological and socio-economic factors. Among the socio-economic causes, a low producer price index was a key issue, albeit indirectly.

In another study, Kyei et al. (2011) examined factors influencing the efficiency of cocoa farmers in Ghana's Offinso district. Data collection involved questionnaires, and the analysis employed statistical tools to estimate production frontier functions and inefficiency determinants. Input factors such as labour, fertilizer, pesticides, modern equipment, tree age, and farm size were analyzed. While labour and tree age showed no significant effects on productivity, inefficiency analysis indicated that most socio-economic characteristics, aside from farmer age, were statistically insignificant. The study recommended optimizing factors like labour, capital, and farm age to boost cocoa production.

Additionally, Anim-Kwapong and Frimpong (2005) analyzed the effects of climate change on cocoa yields using multiple regression techniques. Their findings revealed that over 60% of the variations in dry cocoa bean output were linked to annual rainfall, dry-season rainfall, and sunshine duration from the preceding year. The study identified prolonged droughts, low soil fertility, pest infestations, limited access to improved planting materials, and inadequate farmer incomes as key challenges. They also noted that insufficient income discourages farmers from reinvesting in their farms or adopting innovative practices to counter climate change's effects on cocoa production.

2.4 Adoption of Agricultural Technologies.

Agricultural technology is essential for smallholder farmers to increase their farm productivity and improve the efficiency of their farming operations (Thornton et al., 2017). The process of adopting technology is multifaceted, including the acceptance of the new technology and the modification of existing practices. In this study, adoption of agricultural technology refers to recognizing, implanting and utilizing the current and newly improved methods and tools amied at enhancing productivity and livelihood (Atsriku, 2020). Suri and Udry (2022) noted that adoption of agricultural technology involves the integration of new technologies into already existing practices through experimentation processes and some levels of adjustment. Yan (2020) mentioned that adoption is an alteration in human behaviour with many variations such as social, consumer, entrepreneurial, economic and technological behaviours.

Adoption of agriculture technology and innovation may vary among individual farmers and are likely to change over time depending on many factors. The adoption and diffusion process are linked with factors affecting the adoption or decline by the end users (Rogers et al., 2014). Studies on factors influencing the adoption of agriculture technologies have provided same or different results among the factors. Many successful adoptions occur where the farmers have easy access to adequate extension assistance and supporting infrastructures of the technology (Adebayo et al., 2022). When it comes to farmers using new agricultural technologies and practices, agricultural extension services are important. They are the main means of spreading inventions, but a number of obstacles (financial constraints, cultural barriers) frequently make them less effective (Anil et al., 2024). Additionally, studies show that the effectiveness of extension agents' information and their interactions with farmers has a major impact on how quickly agricultural methods are adopted. Loki (2022) found that, despite the fact that farmers may express skepticism about the services of AEAs, farmers' readiness to embrace technical advice is fundamentally influenced by their confidence in extension service. Furthermore, extension agents could use social media platforms to foster knowledge sharing, indicating that highly connected extension agents may be able to improve farmer participation in the adoption of agriculture technology (Raya et al, 2024). Avane et al. (2022) found that the decision to adopt organic fertilizer in Ghana’s cocoa production is affected by educational level, farming experience, farm size, income, secondary occupation, distance from agro input shop and extension contact.

Ilesanmi and Afolabi (2020) posit that many of the failures of technology adoption are due to the lack of supporting facilities for the technology either due to lack of information, appropriate conditions or lack of extension institutions. A study conducted by Nagar et al., (2024) revealed that training and awareness have a favorable impact on farmers' uptake of technical advice, underscoring the significance of good communication and confidence in extension services. Farmers must receive specific training and assistance from AEAs in order to be empowered and increase their use of technology, which is expected to improve their welfare and production (Asante et al. 2023). It was found by Sadat et al. (2017) that trainees of agricultural technology have much higher knowledge and adoption rates than non-trainees, demonstrating the efficacy of structured training initiatives. Some farmers can be reluctant to use new methods because of sociocultural beliefs and a preference for the old ways (Sousa et al., 2016). Thus, while training is critical for encouraging innovation, it must be adapted to farmers' tastes and socio-cultural situations in order to be most effective (Mgendi et al., 2022).Effective training can transform farmers into proactive innovators, as it could enhance agricultural productivity and sustainability (Ndombi, 2015).

Access to financing has a substantial impact on agricultural technology adoption rates since it alleviates financial limitations that farmers confront when implementing new technologies. Access to credit facilities promotes the use of many agricultural technologies, such as chemical fertilizers and high-yielding cultivars. Furthermore, credit from financial institutions is particularly important in boosting the intensity of usage of these technologies (Regassa et al., 2023). Off-farm income has a major influence on agricultural technology adoption rates, yet the effects vary depending on the environment. Off-farm income often raises farmers' awareness and acceptance of resource-conservation technologies due to enhanced information access and positive cognition about new practices (Huang & Zhu, 2024). While unearned income typically has a negative impact on technology adoption, earned off-farm income favorably correlates with the adoption of capital-intensive technologies (Gedikoglu & Parcell, 2013). Furthermore, research conducted in Ghana indicates that the adoption of hybrid maize is not much impacted by off-farm income, indicating that although it could offer financial support, it could also compete with other sources of labour, thus compromising improvements in productivity (Addai, 2015). As per the findings of Herrera Arango et al. (2023), a number of factors, including family income, loan availability, and market conditions, significantly impact farmers' decisions to implement novel methods. Adoption of integrated agricultural systems, for instance, has been demonstrated to increase small-scale and marginal farmers' income (Srinika et al., 2017). Improved agricultural technologies in conventional chicken farming have also been connected to increased income and the reduction in poverty, underscoring the financial advantages of agricultural technology adoption (Soviadan et al., 2022).

The impact of land size on adoption rates in agriculture is multidimensional, with differing effects reported across different situations (Schulz & Börner, 2023). According to Chauhan et al. (2006), positive correlation exits between landholding size and adoption of improved dairy farming practices, with larger farms demonstrating a greater inclination towards adopting advanced methods. This suggests that larger farms generally facilitate adoptions of modern agricultural practices and technologies. In contrast, Munyao et al. (2013) revealed that the total size of land held had little bearing on the amount of area allotted for its cultivation. Instead, variables including land tenure and the readiness to change the use of the property were more important (Munyao et al., 2013). Studies have shown that land ownership has a major impact on adoption rates in agriculture (Adesida et al., 2021; Zeng et al., 2017). The decision of farmers to adopt risk-coping techniques is influenced by their land ownership status as farmers who owned farm land have greater access to credit facilities than tenant farmers, who depend more on conventional techniques (Ullah et al., 2019). Agricultural technology adoption is hampered by fragmented land ownership, and although voluntary land consolidation is preferred, only a small portion of land has been consolidated because of political and financial obstacles (Aslan et al., 2007). Securing land tenure enables farmers to invest more in their activities, as a favorable correlation between land ownership and on-farm investment and reduction of investment risk (Akber et al., 2024).

The effect of age of household head on the adoption of technologies has diverse outcome. Older farmers may be more inclined to adopt new practices due to their accumulated experience and knowledge, as noted by Simtowe, et al. (2016). Conversely, Brown et al. (2019) argued that older farmers often exhibit conservative tendencies, which can hinder their willingness to embrace new or improved technologies. This duality is echoed in findings from Nyirahabimana et al. (2021), who indicated that while age can influence adoption practices, the relationship is nuanced and may vary based on other factors such as household size and access to resources. Adoption rates in agriculture are heavily influenced by farm experience, with different effects based on the setting and techniques. It has been demonstrated that community-integrated experiential learning programmes in Eastern and Southern Africa boost the adoption of conservation agricultural practices, indicating that practical training raises the chance of embracing new techniques (Marenya & Usman, 2021). Moreover, farmers with more years of experience showed increased awareness and adoption rates of sustainable agricultural techniques, underscoring the significance of experience in promoting creativity and awareness (Ashrit & Thakur, 2021). However, Kernecker et al. (2020) found that the impression of new technologies, such as smart farming, varies among farmers, with both adopters and non-adopters expressing skepticism, highlighting the difficulties of integrating experience with new agricultural innovation. In a study by Akinwale and Folarin (2018) on the factors that influence farmers' adoption of cocoa hybrid technology in Oyo State, Nigeria, they found farmer's age and farming experience are the factors that influenced farmers' likelihood to adopt hybrid cocoa.

Gender dynamics have a major impact on adoption of agricultural technologies in Ghana, especially in the production of cocoa, (Teye et al., 2024). Women have significant resource limitations, such as restricted access to finance and land, which makes it difficult for them to successfully adopt new technology (Anil et al., 2024). Men often have more access to productive assets, according to Sennuga. et al. (2020), which accounts for the gender disparity in land ownership, which can reach 80% in favor of men. Due to their frequent exclusion from important agricultural advances, women's participation in decision-making and adoption of agricultural technologies are impacted by this discrepancy. Household size has a substantial impact on adoption rates in agriculture, with bigger households frequently adopting lower rates of improved agricultural methods. It was observed by Amaza et al. (2007) that greater family sizes were inversely connected with the adoption of better maize varieties, implying that these households may prioritize non-farm activities above agricultural advancements. Munćan and Božić (2017) suggested that larger family size may benefit from increased labour availability, resulting in higher production and income per member. However, the relationship between family size and adoption is complicated as larger families may have more labour, but they may also face competing demands that prevent them from adopting new technology (Ayaz & Mughal, 2024).

The adoption of agricultural technologies is influenced by Farmer Based Organizations (FBO) (Harikrishna et al., 2022). Ganeshkumar et al. (2023) claimed that FBOs are essential for promoting agricultural technology, knowledge and increasing adoption rates. Similarly, it was observed by Kehinde et al., (2022) that membership in agricultural groups is positively correlated with improved implementation of soil conservation techniques, which in turn had a favorable impact on the adoption of these practices. Other studies have showed that combination of factors also has influence on the adoption of agriculture technology among farmers. Tamirat and Abafita (2021) explored the factors influencing adoption decisions and their effects on income and expenditure. Their binary logit regression analysis indicated that variables such as age, family size, education level, income from off-farm activities, land ownership, famer training, access to credit and extension services significantly influenced farmers participation in any agricultural technology. Similarly, Belay and Mengiste (2023) analyzed how adopting agricultural technologies contributes to reducing poverty. Their findings showed that the key factors that drives the adoption decision of farmer households include gender of the household head, membership of a farmer cooperative, proximity to markets, access to credit and extension services.

Ilesanmi and Afolabi (2020) identified key factors influencing the adoption of improved cocoa technologies to include gender, education level, information sources and visits from extension agents. Bosompem (2019) averred that the adoption of agriculture technologies was influenced by farmers' educational level, access to credit facilities, and the perceived advantages of the technology. Similarly, Ali and Danso-Abbeam (2018) found factors such as participation in off-farm economic activities, farm size, hired and family labour, access to agricultural extension services and value of productive farm assets were significant in determining the adoption of fertilizer among smallholder cocoa farmers. Djokoto et al. (2016) observed that males, smaller household size, younger cocoa trees, access to credit and extension services positively influenced the adoption of organic cocoa technologies. Lastly, Nabhani et al. (2016) emphasized that competitiveness pressure and perception were critical factors influencing cocoa farmers' technology adoption decisions.

2.5 Perception of farmers on agricultural technologies

The perception of farmers on existing or improved technologies plays a crucial role in determining their willingness to adopt such technologies. The knowledge an individual possesses about such new technology serves as the foundation for forming perceptions towards it. A farmer's perception of a technology is closely tied to their understanding of its functions and benefits. While knowledge encompasses factual details and an understanding of how a technology operates and what it can accomplished, perceptions are the individual needs, prior experiences, and personal viewpoints. The perception of farmers on their use of advance technologies influences their decision to either adopt the technology or not to adopt it. These perceptions are often based on how the technology is perceived to address their specific needs and challenges such as perceived risk (pests and diseases), perceived benefit (contribution to income, food security, improvement in soil fertility), and the production cost (purchasing inputs, equipment) that comes with a particular technology (Jha et al.,2021; Mottaleb, 2018).

Jha et al. (2021) has indicated that perceptions are influenced by the characteristics of the farmer, which include personal attributes (gender, age, and marital status), socio-economic factors (income, assets, and education), social networks (network size, connectedness, and frequency of interaction), personality traits (self-confidence, independence), status indicators (control over political power or economic resources) and familiarity with the technology. In addition, the external environment also plays an important role in the development of an individual's perception. These include geographical factors (ecology, topology, soil conditions, climate, and demography, proximity to markets, roads and forests.), societal culture (language, ideologies, and norms, values tribal and religious affiliations) and political conditions (land tenure and access rights, policies). Knowledge on how farmers perceived cocoa pollinators is essential in encouraging farmers on how to manage their cocoa farms and practice agri-environmental initiatives (Meijer et al., 2015). Farmer's perceptions play a crucial role in agriculture for is sustainable and environmental conservation in sustainable farming (Rawluk & Saunders, 2019).

Misganaw et al. (2017) investigated the perception of farmers on insect pollinators in the Gozamin district in Ethiopia. Using household surveys (131 respondents), transect sampling, focus group discussions, and field observations, the study found that 77% of farmers were unaware of pollination or its significance. Over 62% of respondents only recognized honeybees as pollinators, and 83 participants could not identify their role in seed production. Despite this, 75 farmers showed awareness of the adverse effects of insecticides and herbicides on pollinator activity. Most farmers, however, were disinterested in pollination, believing it would reduce yields due to challenges such as pesticide use, drought, and deforestation. The study emphasized the need to raise awareness about the importance of pollinators and their conservation among farmers.

Agbongiahuoyi et al. (2014) explored how Nigerian cocoa farmers perceive voluntary standard certification. Using purposive sampling, they selected 80 farmers from Cross River and Osun States, regions familiar with cocoa certification practices. Data was gathered through structured interviews and analyzed using descriptive statistics and correlation. Their findings revealed that 87.5% of the interviewed farmers were aware of voluntary standard certifications, particularly Rainforest Alliance and UTZ. Additionally, 32.5% of respondents reported receiving certification training from UTZ-affiliated exporters, while 67.5% believed the government's Cocoa Transformation Agenda (CocTA) would support certification practices. However, low perception towards certification was linked to socio-economic factors such as farm size, age, experience in farming, and yield, which significantly influenced farmers' views ($p < 0.05$). The study recommended integrating socio-economic factors into CocTA policies and training programmes to promote sustainable cocoa production.

Similarly, Frimpong-Anin et al. (2013) conducted a survey to assess farmers' and agricultural extension officers' knowledge of cocoa pollination and its potential impact. This research, carried out in Ghana's cocoa-growing areas (Kubease-Wuraponso, Abrafo-Ebekawopa, and Edwenease), used structured questionnaires to gather data from 112 participants across 97 farms. Their results showed that 87.6% of respondents lacked an understanding of pollination, often perceiving it as an intrinsic tree mechanism. Again, 82.5% believed pollination was unnecessary for fruit set, 12.4% demonstrated an understanding of its basics while 5 out of 12 farmers could identify cocoa pollinators as key species. However, knowledge about midges and their reliance on cocoa pod husks for breeding was low. The study attributed this lack of awareness to low educational levels in the surveyed regions and did not examine how this knowledge gap affected cocoa yields.

2.6 Impact of technology adoption on productivity

According to Ayenew et al. (2020), adoption of agricultural technologies significantly enhances agricultural productivity, ensures food security, and alleviates poverty in farming communities. Wossen et al. (2019) asserted that the creation, dissemination, and adoption of advanced technologies by smallholder farmers are crucial for increasing their productivity and livelihoods However, the success of these technologies depends largely on the willingness of farmers to adopt them and the rate at which these technologies are embraced (Zegeye et al., 2022). Rogers et al. (2014) stated that technologies with higher adoption rates are often perceived to have advantages such as greater compatibility, divisibility, observability and ease of use.

According to Zegeye et al. (2022), the adoption of improved agricultural technologies can result in higher level of productivity, improved household and national food security, and reduced rural poverty by increasing the income and consumption of smallholder cocoa farmer. Mekonnen (2017) highlighted the positive and significant impact of adopting advanced agricultural technologies on crop productivity and farmer's welfare. Similarly, Gebeyehu (2016) found that adopting improved seeds, agricultural capital, family labour, and organic manure positively influenced crop yield, whereas farm size and chemical inputs had negative and significant impact. Shita et al. (2020) investigated the relationship between agricultural technology adoption and income inequality using propensity score matching methods. The results revealed that adopting inputs like improved seeds and fertilizers significantly boosted household income of smallholder farmers. Additionally, Wordofa et al. (2021) examined the impact of agricultural technology adoption has on household. Ayenew et al., (2020) indicated that adopting agricultural technologies is essential for enhancing productivity, improving household welfare, reduce poverty and increase food self-sufficiency (Teka & Lee, 2020).

Alao and Shuaibu (2013) emphasized the role of agroforestry technologies in enhancing farm productivity and environmental resilience. Their study showed that farmers often retain naturally regenerated trees on farmlands while also planting improved species to increase tree populations. This system provides multiple benefits, including access to food, fruits, and supplementary income, while offering shade and mitigating adverse climatic and environmental conditions. Importantly, the long-term effect of this practice is the improvement of soil fertility, which ultimately contributes to increased agricultural yields.

Several studies have highlighted the significance of technology adoption and socioeconomic factors in improving coffee productivity. Wambua et al. (2021) found that off-farm income, access to credit, land tenure arrangements, and land size positively influenced coffee yields in Kenya, as revealed through a stochastic Cobb–Douglas production model. Adoption of appropriate manure, fungicide, and pesticide application rates also proved crucial in enhancing productivity, pointing to the need for encouraging smallholder farmers to embrace such technologies alongside supportive policy reforms. Megdelawit and Sisay (2023) investigated adoption dynamics of improved coffee varieties and management practices in the Jimma Zone using a multivariate probit model. Their results revealed that adoption rates and intensity were higher for improved coffee varieties compared to management practices, with decisions influenced by institutional and resource-related factors. These findings suggest that promoting a combination of improved varieties and management technologies can reduce disease vulnerability and increase yields.

Tesfay (2024) further examined the impact of improved coffee varieties on smallholder productivity in northwestern Ethiopia using descriptive statistics and propensity score matching (PSM). The study revealed that adopters were more likely to allocate larger plots of land to coffee, implement soil and water conservation practices, and access financial services and training compared to non-adopters. Education levels were also higher among adopters. The PSM results showed a significant productivity gain of 64.2% among adopters, underscoring the potential of improved varieties to enhance household welfare.

Ariyanto et al. (2020) demonstrated that smallholder oil palm farmers who adopted all recommended technologies achieved higher production efficiency than those who did not. This highlights the importance of both technology adoption and institutional support in oil palm production systems.

The cashew sector similarly benefits from targeted technology adoption and supportive environments. Sajeev et al. (2014) reported that productivity could be significantly enhanced through soil and water conservation techniques, improved plant protection measures, viable intercropping, and orchard management practices such as pruning and training. However, they noted that socioeconomic, biophysical, and policy-related factors exerted a greater overall influence on cashew productivity than technology adoption alone. Nnahiwe et al. (2023) analyzed cashew farming in Kenya's Coastal Province using logit and multiple regression models. Their findings indicated that access to extension services and group membership positively influenced the adoption of fertilizers, pesticides, and appropriate planting densities.

These results highlight the complexity of technology adoption outcomes in tree crop farming, shaped by both agronomic practices and socioeconomic conditions.

2.7 Review of methodologies of previous related studies

In previous studies different methods have been used to analyze farmers' perceptions, adoption of technologies, and the impact of these technologies on agricultural outcomes. The methods range from simple descriptive statistics and Likert scales to more advanced econometric models like the Multivariate Probit, Tobit, Heckman, and Cragg Double Hurdle models. These methods effectively assess perceptions, adoption decisions, and the impact of agricultural technologies on farmer welfare and productivity. The use of advanced econometric models like Tobit, Heckman, and Double Hurdle provides robust insights, while descriptive statistics and perception indices offer a broad understanding of farmers' views.

The multivariate probit has been used to study the adoption of multiple agricultural technologies in maize production in Ethiopia (Ahmed, 2015). This study used a multivariate probit model to analyze the adoption of multiple agricultural technologies such as improved seeds, fertilizers, and crop management practices by smallholder farmers in Ethiopia. The model accounted for the interdependence of adoption decisions across different technologies. The multivariate probit was also used to study the factors influencing the adoption of sustainable agricultural practices in developing countries (Tey, 2017). The Tobit model was employed to analyze the intensity of technology adoption among Indian farmers, focusing on factors such as education, access to credit, and extension services (Das & Das, 2017). The Tobit model is used with the assumption that the two decisions are affected by the same set of factors. The underlying assumption of the Tobit model is that farmers demanding modern inputs have unconstrained access to the technology (Yu & Nin-Pratt, 2014). Therefore, the Tobit model is inappropriate in situations where some portion of farmers are constrained to access new technology and other portions of farmers are not considering the new technology.

The Heckman selection model is also another alternative model used to analyze the intensity of technology adoption. In the Heckman model, the non-adopters are considered as they will never adopt under any circumstances. Hence, Heckman selection model is restrictive in the sense that non-adopters might be encouraged to adopt for various reasons like access and improvements in extension programmes and changes in input prices. In a study by Degaga et al. (2020), the researchers used Heckman model to determine the factors affecting adoption of improved haricot bean in Ethiopia. The double hurdle model which was proposed by Cragg (1971), assumes that non-adopters are considered as a corner solution in a utility-maximizing model. This model gives room for factors affecting the two decisions to differ as it models the decision process in two separate steps. It also considers the possibility of zero observation in the second stage of decision which may arise from an individual's choice or random circumstances. In a previous study, Ndah et al. (2014) used the double hurdle to examine the adoption potential of conservation agriculture practices in sub-Saharan Africa.

In a study to assess the impact of microcredit on agricultural households Mahmud et al. (2022) and Wadud (2013) employed Randomized Controlled Trials (RCTs). Randomized Controlled Trials are considered the standard due to their random assignment of participants to treatment and control groups, minimizing selection bias. Azumah and Zakaria (2019) used Difference-in-Differences to evaluate the impact of fertilizer subsidy and rice productivity in Ghana. Difference-in-Differences compares changes in outcomes over time between a treatment group and a control group, controlling for time-invariant unobserved heterogeneity, but it requires the parallel trends assumption (Sant'Anna & Xu, 2023). Wordofa, et al. (2021) evaluated the adoption of improved agricultural technology and its impact on household income using the propensity score matching estimation. In estimating the impact of technologies adoption in farming, Samanta (2023) employed the propensity score matching. Propensity Score Matching (PSM) mimics randomization by matching treated and control units with similar propensity scores, yet it can be biased due to imperfect matching and does not account for unobserved confounders (Kane et al., 2020; Wordofa, et al., 2021). Regression Discontinuity Design (RDD) exploits a cutoff point to identify causal effects, providing a clear criterion for treatment assignment, but it is limited to cases where a clear cutoff exists and may have limited external validity (Wuepper & Finger, 2023).

2.8 Pollination and Cocoa Pollinators

Pollination involves moving pollen from a flower's anthers to its stigma, where it germinates, and pollen tubes develop within the style to fertilize ovules. This process is facilitated by pollinators such as birds, bees, bats, butterflies, moths, beetles, and other animals, or by wind (Bastiaan 1984). However, research into cocoa pollination has been limited, with wind generally dismissed as a significant factor due to the weight and tendency of cocoa pollen to clump, making wind transport unlikely (Claus et al., 2018). Furthermore Soria et al. (1980) demonstrated that increasing air currents artificially using motorized sprayers could boost pollination in self-compatible cocoa varieties, effectively doubling yields (Soria et al., 1980). Insects are the primary pollinators of cocoa, with midges from the Ceratopogonidae family (1–4 mm in length) playing a key role. Winder (1977) reviewed five studies and concluded that female midges are the main cocoa pollinators, although Kaufmann (1975) noted that male midges are more numerous but less effective in pollination. Female midges are particularly drawn to cocoa flowers due to the protein-rich pollen, which supports egg development.

Historically, sampling cocoa-pollinating midges involved cutting flower pedicels and dropping them into ethanol to collect insects (Lopez et al., 2021; Billes, 1941). However, Posnette (1947) identified inefficiencies in this method, observing that insects often escaped before the flowers reached the ethanol. Posnette's improved technique involved enclosing flowers and midges in specimen tubes, ensuring successful collection. Despite its effectiveness, this method remains challenging due to the difficulty of capturing insects and their tendency to escape. Given the importance of pollinators for crop yields, Frimpong et al. (2009) emphasized the need for effective tools and methods to study cocoa pollinator populations. They developed protocols using UV-painted traps, McPhail traps, and motorized aspirators to monitor cocoa pollinators in Ghana over 13 months. They found that ceratopogonid midges were most active from 07:00 to 12:00 and that UV-painted traps were particularly efficient. However, the diversity of midges captured was not analyzed. To address this gap, Frimpong et al. (2011) focused on the dynamics of cocoa pollinators, particularly ceratopogonid midges, in smallholder farms across Ghana. They found a positive correlation between the presence of plantains and cocoa pollination and recommended further research on spatial arrangements of intercropping to enhance pollination. Although ceratopogonid midges are the dominant pollinators, other insects like gall midges, non-biting midges, fruit flies, dung flies, and moth flies contribute minimally to pollination (Winder, 1977; Frimpong et al., 2011).

Research by Bridgemohan et al. (2017) highlighted the importance of midges for cocoa productivity. Their studies revealed that substrate augmentation using cocoa pods and banana pseudostems could significantly increase pod production per tree, indicating that discarded cocoa pods are effective breeding sites for midges. Cocoa yields rely on successful pollination rather than nutrient availability as confirmed by Groeneveld et al. (2010). Hence there is the need to understand the pollination ecology and pollinator behaviour in addressing the yield deficits. For example, cocoa flowers are structurally complex and produce volatiles that attract pollinators, as observed by Young and Severson (1994). Moreover, cocoa flowering patterns are influenced by precipitation and pod harvesting, which triggers additional flowering (Glendinning, 1972; Bos et al., 2007).

2.9 Concept of pollinator technology (breeding substrate)

According to Saripah and Alias (2018) yield of cocoa increases with successful pollination of cocoa flowers, hence the need to increase the population of pollinators in the farm during the flowering period. In natural environmental conditions, species such as *forcipomyia spp*. and other *ceratopogonid midges* breed and complete their life cycle in decaying organic materials (Arnold et al., 2019; Zakariyya et al., 2016). The midges can travel a distance of 50 meters (Frimpong-Anin et al., 2014; Glendinning, 1972) to complete floral pollination, hence more breeding sites should be created on the farm to reduce the search time to increase the pollination rate on the cocoa farm (Holland & DeAngelis, 2002). The breeding technique in pollinator technology is breeding for cocoa-pollinator midges with the use of rotten, moist organic material as breeding substrate.

The reproduction of cocoa pollinating midges can be improved by incorporating organic materials into the cocoa farms as breeding substrate (Adjaloo et al., 2013). Midges are highly dependent on decaying organic materials and providing additional breeding substrates promotes the development of stable pollinators in the cocoa farm (Arnold et al., 2019). The substrate could be made from plantain/banana pseudo stems (Figure 2.1b), piles of cocoa leaf litters and cocoa pod husks (Figure 2.1a) which can serve as breeding sites for the midges (Frimpong-Anin & Kwapong, 2020; Saripah & Alias, 2018). While Adjaloo et al. (2013) and Frimpong et al. (2013)

established that the use of plantain/banana pseudo stem is the most preferred in increasing the population of cocoa pollinator midges and pod-set on cocoa farms, Frimpong-Anin & Kwapong (2020) and Forbes & Northfield (2017) identified cocoa pod husks as a preferable cocoa breeding substrate that increases pod setting and yield. Similarly, Toledo-Hernández et al. (2021) indicated that, the population of the midges for cocoa pollination is related to the leaf litters which serve as the habitat and the most appropriate substrate for midge activity for high yields. These observations suggest that different species of midges might have different substrate preferences depending on the location and ecosystem.

Providing a breeding substrate for cocoa pollinator enhancement can be done with the use of container, digging holes on the farm and heap/spreading of the substrate materials. According to Saripah and Alias (2018), a plastic substrate container (Figure 2.2) with holes of about 0.5 metres in diameter is placed at areas with low pollinator population. The holes in the container are to aid ventilation and discharge from the decaying substrates. Vanhove et al. (2020) indicated that holes measuring 0.5 meters in width and length, and 0.3 meters deep could be excavated on the cocoa farm in a square grid pattern at a spacing distance of 10 meters for substrate breeding. Frimpong-Anin and Kwapong, (2020) heaped substrate materials at about 1-2 meters high for substrate decay in breeding for the midge pollinators.

Figure 2.2: Substrate materials (Cocoa pods, leaves and plantain pseudo stem)

Figure 2.3: Hanging of containers for breeding pollinator substrate

The selected pods for the substrate breeding should be disease free to prevent the spread of black-pod on the farm (Adjaloo et al., 2013). Boateng et al. (2023) indicated that agrochemicals are widely used in cocoa farming. While agrochemicals such as insecticides, pesticides and fertilizer are key inputs used in controlling pests and diseases to improve cocoa productivity, incorrect use of these agrochemicals can cause harm to human health, the environment and cocoa pollinators, which can in turn affect the cocoa yields. According to Claus et al. (2018) habitat destruction of cocoa pollinators through unsustainable pest management practices such as insecticide misuse negatively affects the overall population of pollinators. This is further confirmed by Sponsler et al., (2019) who stated that the factors that could cause toxicity of agrochemicals to cocoa pollinators are dosage, mode of application, and timing of application.

2.10 Pollination services and conservation

Insect pollinators play a crucial role in human well-being by supporting the reproduction of wild plants and maintaining ecosystem health and functionality (Potts et al., 2016; Kleijn et al., 2015). They form the foundation of sustainable livelihood, connecting ecosystems globally (Hill et al., 2019). Consequently, protecting insect pollinators is crucial for achieving the United Nations Sustainable development goals (SDGs). For example, pollination contributes to no poverty, by enhancing crop yields, leading to income for smallholder famers. It also supports zero hunger by improving crop yields and enhancing the nutritional value of fruits and seeds. Additionally, pollinators play an important role in the life on land by supporting biodiversity through the pollination of flowering plants and trees, which contributes to forest conservation. Understanding the importance of pollination services is vital for conservation planning to achieve biodiversity, sustainable development targets and long-term food security (Christmann, 2019).

Pollination services in cocoa farming are particularly important because it has a direct effect on farmers' livelihoods and also considered as pollinator-friendly and conservation modules to enhance production (Frimpong et al., 2013). Development of cocoa pods relies on effective pollination, which depends on the availability of pollinating insects (midges). Thus, creating favourable environmental conditions for these insects is essential to maximize cocoa production (Dani & Rokhmah, 2022). Improving knowledge on the relationship between sustainable cocoa production and pollination services will help adapt strategies for pollinator management and sustainability (Tolera & Ballantyne, 2020). Documenting accurate information on pollinator dependent crops, pollinator diversity and abundance will also aid in identifying pollination crises and better-target conservation measures (Tibesigwa et al., 2019). It is essential to develop innovative strategies for managing pollinators in ever changing agro-ecosystems without jeopardizing agricultural production (Mwangi and Kariuki., 2015).

Pollination challenges in cocoa often necessitate the use of pollinator technologies, such as breeding substrates, as a strategic agricultural intervention. Pollination may fail or become insufficient—referred to as pollination failure, deficit, or limitation—when inadequate quality or quantity of pollen is transferred to the cocoa flower, or when pollination does not occur at all (Wilcock & Neiland, 2002). These challenges significantly impact cocoa yields and have broader conservation implications (Lippert et al., 2021). Pollination limitations in cocoa production are evident when natural pod set rates are lower compared to those achieved with pollinator technology (Minarro & Twizell, 2015). Factors contributing to these limitations include declines in pollinator populations, changes in land use, invasive species, or random fluctuations in pollen availability (Wurz et al., 2021). Pollination limitation can threaten subsistence as well as causing severe socioeconomic consequences (Christmann, 2019). Pollinator technology can act as a safeguard, either by supplementing or entirely augmenting natural pollination in areas or periods where pollinators are scarce or unreliable. This approach is particularly valuable when pollinators conservation is limited (Baldock, 2020), during ecosystem restoration efforts

(Kremen & M'gonigle, 2015), or in situations where knowledge or funding for conservation is lacking (Marques et al., 2017; Eardley et al., 2009). As a result, pollinator technology provides an effective management tool to address pollination challenges.

2.11 Summary of Literature Review and gaps identified

The literature reviewed highlights the importance of cocoa production in Ghana's economy, with the persistent challenge of low productivity relative to potential yields largely due to aging cocoa trees, declining soil fertility, poor management practices, pest and disease pressures, and climatic variability such as prolonged droughts. While technology adoption has been shown to enhance productivity, its effectiveness is strongly influenced by farmer perceptions, socio-economic characteristics, access to extension services, and institutional support. It establishes that cocoa productivity in Ghana is low and that pollination is a critical but under-researched factor. Experimental studies confirm the potential of pollinator technologies (breeding substrates), but there is limited evidence on farmer adoption, the socio-economic drivers of adoption, and the quantifiable impacts on cocoa yields and livelihoods. The study therefore fills a critical gap by examining how adoption of pollinator technology affects cocoa productivity in Ghana, while also addressing farmer perceptions, constraints, and enabling factors.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

In this chapter the methodology employed for the study is described. First, the theoretical framework is presented, followed by the conceptual framework, method of data analysis, method of data collection, sampling and lastly the study area.

3.2 Theoretical framework

Different theories have been proposed and examined to understand the factors influencing farmer's adoption of traditional and advanced agricultural technologies. The study of agricultural technology adoption integrates aspect of decision theory and the diffusion of innovations framework to explore why certain farmers embrace new or improved technologies (Karbo et al., 2024). This research employed the Theory of Planned Behaviour (TPB), the Diffusion of Innovation Theory and the Technology Acceptance Theory to assess adoption of pollinator technology (breeding substrates) among cocoa farmers.

3.2.1 The Theory of Planned Behaviour (TPB)

This is a socio-cognitive theory widely used in different disciplines and context to provide an understanding of human behaviour (Ajzen, 1991). The TPB has been effectively utilized to study professional development, teaching practices, and changes in teaching and learning, especially within the discipline of science, technology, engineering and mathematics (STEM) (La Barbera & Ajzen, 2021). The TPB suggests that behavioural intention has a direct impact on behaviour and intention is influenced by attitude, subjective norm, and perceived behavioural control (Mawar & Adiati, 2024). Attitude refers to a person's favorable or unfavorable perception of the behaviour (Aishi et al., 2020). Subjective norm is conceptualized as an individual's perception of their peers' approval or disapproval of behaviour (Purwanto & Rini, 2022). Perceived behavioural control refers to a person's belief in their ability to carry out specific behaviour and their control over it (Puspita, 2023). According to TPB, for a behavioural intention to manifest as actual behaviour, the individual must possess the necessary ability to execute the behaviour. Thus, perceived behavioural control is hypothesized to directly influence actual behaviuor.

The main strength of the TPB is that it provides a comprehensive framework for explaining behavioural intentions by integrating attitudes, subjective norms, and perceived behavioural control. This makes it particularly relevant to agricultural technology adoption, where farmers' decisions are influenced not only by knowledge but also by social expectations and perceived constraints. The model's inclusion of perceived behavioural control helps to explain why high awareness does not necessarily lead to adoption, as farmers may lack the resources or required training to implement the technology. Despite its usefulness, the TPB assumes that individuals make rational choices, which may not fully reflect farmer behaviour in settings where decisions are shaped by tradition, cultural influences, and risk aversion.

3.2.2 Diffusion of Innovation Theory

Diffusion of Innovation Theory, articulated by Rogers (1995), describes how new ideas and technologies spread within a social system over time. According to Rogers et al. (2014), the rate of adoption of a technology by an individual depends on the relative advantage, compatibility, complexity, trialability and observability. This theory examines how innovation is spread through specific channels over time within the social system. Communication channels are the means by which information about an agricultural technology is disseminated to and among cocoa farmers (Tham-Agyekum et al., 2024).

This explores the effectiveness of various communication channels, such as agricultural extension services, workshops, media and informal farmer networks in spreading awareness and knowledge about the technology. The adoption process is inherently time-based, involving the innovation-decision process. It begins with the farmer gaining knowledge about the technology, followed by forming a perception about it. This leads to a decision whether to adopt or reject the technology followed by its practical application, and confirmation of this decision (Anand et al., 2014). This analyzes the adoption timeline and identifies the stages at which farmers are currently situated. The social system encompasses the community of cocoa farmers and how they interact (Bosselmann et al., 2023). The social system affects the diffusion of innovation in various ways, including the norms of the system, the roles of opinion leaders, and the type of innovation-decision (optional, collective, or authority-based) (Matous & Bodin, 2024). Opinion leaders influence the diffusion process by shaping the perception and guiding bahaviour within the social systems. In the context of this study, agricultural extension officers and influential farmers such as the chief farmers often serve as opinion leaders (Hameed & Sawicka, 2017, 2023). Collective decisions where groups adopt an innovation together, often lead to slower but more sustainable diffusion due to varied views on deliberations (Leeuwis & Aarts, 2020). In contrast, authority-based decisions can lead to rapid adoptions.

The theory has the strength in identifying attributes of the innovation that influence adoption behaviour. It also emphasizes the role of social networks, opinion leaders, and communication channels, which is particularly relevant in rural farming communities where peer learning is strong. Additionally, the categorization of adopters into innovators, early adopters, early majority, late majority, and laggards helps in understanding adoption trends over time. However, the theory tends to assume that innovations diffuse naturally once introduced, without adequately considering institutional, financial, or policy related barriers. This may oversimplify the realities of smallholder farmers who face constrained access to credit, extension services, and labour.

3.2.3 Technology Acceptance Model (TAM)

The TAM by Davis (1989), include user motivation variables of perceived usefulness, perceived ease of use and outcome variables like behavioural intention, and actual technology use. According to Marangunic and Granic (2015) perceived ease of use and perceived usefulness are the main variables that influence behaviour and intention. Perceived ease of use refers to the effort required to use a technology, whereas perceived usefulness relates to the outcomes and advantages of using a technology. These beliefs are influenced by external variables including contextual factors and personal capabilities which explain their variation such as self-efficacy, subjective norms and facilitating conditions (Schepers & Wetzels, 2007).

TAM has been applied to the adoption of biological control in farming (Bagheri et al., 2016), precision agriculture (Far & Rezaei-Moghaddam, 2017) and organic farming (Läpple & Kelley, 2013). The main limitation of TAM is that it does not consider the social influence on technology adoption. In addition, TAM does not address factors relating to extrinsic motivations. This makes the model inappropriate where technology use is not only to achieve specific tasks but also to meet certain emotional needs (Taherdoost, 2018). The TAM is widely recognized for its simplicity and empirical validity as strength. Its central constructs; perceived usefulness and perceived ease of use offer clear explanations for individuals' attitudes towards new technologies. These constructs are particularly relevant for assessing perceptions of pollinator technology and help to explain why farmers who find the technology beneficial and easy to apply are more inclined to adopt it. Nonetheless, TAM overlooks several important factors, including social influence, cultural norms, and institutional constraints which serve as weakness to the model. Unlike TPB or diffusion of innovation, the model does not account for financial, policy, or environmental barriers, which significantly affect adoption in smallholder farming systems.

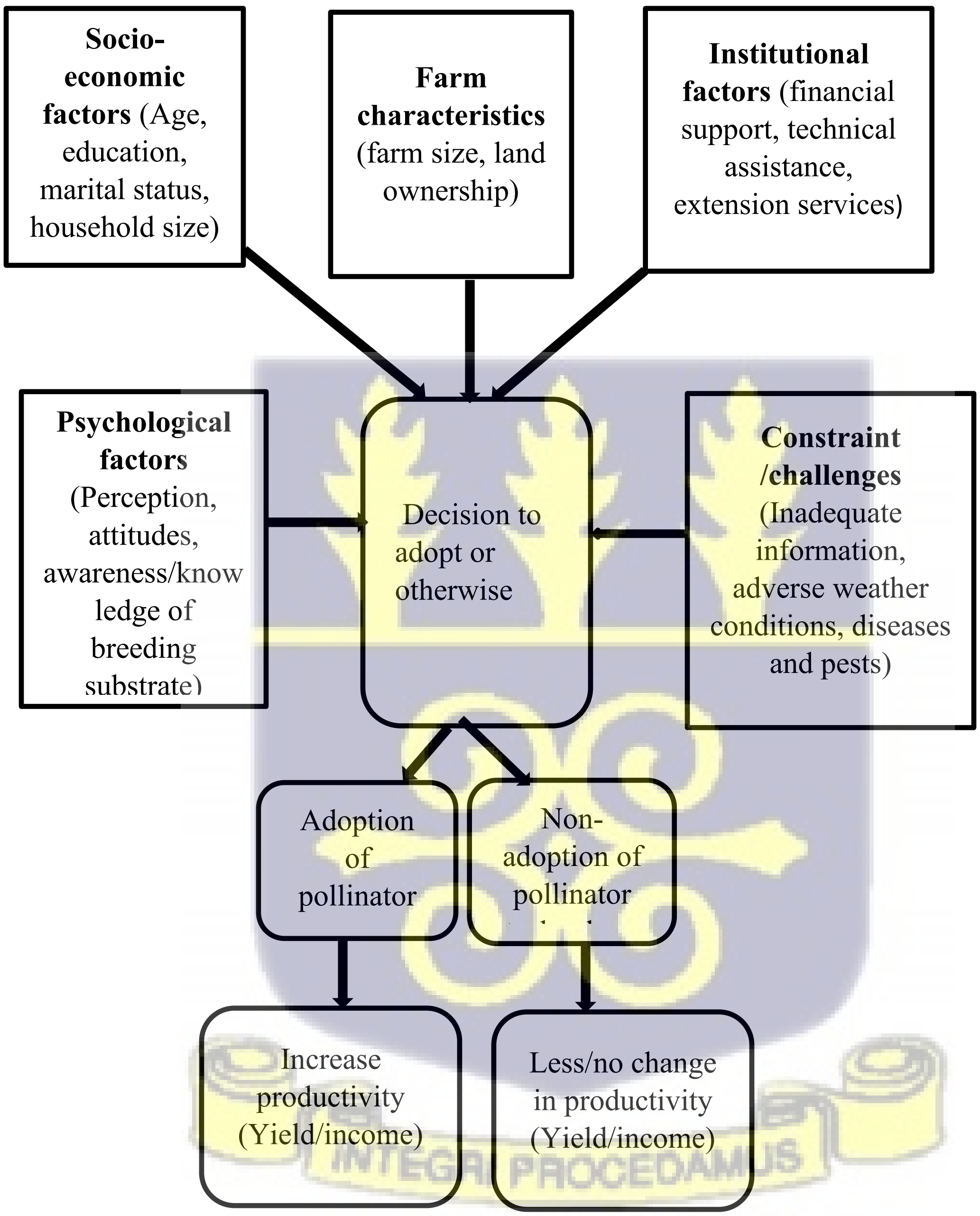
By integrating the TPB and the Diffusion of Innovation Theory, this study provides a comprehensive understanding of the factors that influence cocoa farmers' perceptions, and adoption behaviours regarding breeding substrates for cocoa pollinators. The TPB elucidates the psychological and social dimensions of decision-making processes, and the Diffusion of Innovation Theory contextualizes these processes within the broader framework of technology adoption and diffusion, while TAM predicts, if, and how behavioural intentions influence a potential user to adopt innovative technologies.

3.3 Conceptual Framework of the Study

The conceptual framework presented in Figure 3.1 explains the complex interplay of factors affecting the productivity of smallholder cocoa farmers, with a particular focus on the adoption of pollinator technology. Socio-economic factors (age, education, marital status, household size income), farm characteristics (farm size and land ownership) and institutional factors (technical support, extension service, access to finance) are pivotal in shaping farmers' ability to adopt and effectively utilize pollinator technology (Acheampong et al., 2021). Socio-economic factors such as age and education influence a farmer's readiness and capability to implement new practices, while farm size affect the resources available for technology adoption. Institutional factors are essential in influencing the broader context for adoption of technologies (Phillips & Phillips, 2001). Institutions that provide financial support, technical assistance, and educational resources can help address constraints, enhance farmers' knowledge, and facilitate the adoption of pollinator technology. Access to agricultural extension services is important in providing necessary support and information (Kalogiannidis & Syndoukas, 2024). By fostering an environment conducive to learning and innovation, institutions can significantly boost cocoa productivity and improve the livelihoods of smallholder. The adoption of pollinator technology is influenced by psychological factors, including perception and awareness of its benefits (Wongnaa et al., 2021).

Constraints to adoption, including financial limitations, lack of access to technology, inadequate knowledge, and resistance to change, are significant barriers. Challenges such as adverse weather conditions, and diseases faced by farmers further shape the outcomes of technology adoption (Akudugu et al., 2023). These challenges can impact both the ability to implement pollinator technology and the effectiveness of its impact on productivity. Farmers facing financial constraints may struggle to invest in pollinator technology, while those lacking access to relevant technology or training might not fully leverage its benefits. Akinwale and Folarin (2018) found that high cost of agrochemicals is a major constraint towards the adoption of hybrid cocoa. Insufficient knowledge about the advantages and proper use of pollinator technology can hinder its adoption due to entrenched practices or skepticism about the technology (Elisante et al., 2019). Effective adoption of this technology can lead to improved cocoa productivity. Enhanced productivity by increased pollination efficiency leads to better pod set and development, and optimized nutrient allocation to the cocoa (Forbes & Northfield, 2017).

Figure 3.1: Conceptual framework



Source: Field survey, 2024

3.4 Research Design

The study employed a quasi-experimental research design within a quantitative framework to examine the causal relationships between the adopters and non-adopter's outcomes. This design was selected because it enables the assessment of treatment effects in real-world settings where random assignment is not practical or ethical. Unlike true experimental designs, which rely on randomization, the quasi-experimental approach allows for the use of naturally occurring groups, thereby reflecting more realistic field conditions.

In this study, participants were categorized into treatment and comparison groups based on their adoption of PT rather than through random assignment. This structure made it possible to evaluate the differences in outcomes between the two groups while controlling for pre-existing characteristics as much as possible. The design thus provided a practical means of estimating causal effects while acknowledging the limitations inherent in non-randomized settings.

Data were collected through structured questionnaires and analysed using appropriate statistical techniques to determine the magnitude, direction, and significance of relationships among the key variables. The use of a quantitative approach ensured objectivity, precision, and replicability in the measurement and analysis of data.

3.5 Method of Data Analysis

This section describes the various methods used to analyze the specific objectives under study and explanation of various variables. McDonald (2009) explained that data analysis involves processing a dataset to derive meaningful information, which is presented in formats such as diagrams or tables. The data collected from the farmers was screened for completeness, coded and analyzed using Stata version 17. Statistical techniques such as the descriptive statistics and regression were used for assessing the impact of pollinator technology on the productivity of smallholder cocoa farmers at the Osino cocoa district.

3.5.1 Analyzing the perceptions of farmers on pollinator technology

To achieve the first objective of this study in determining the perception of cocoa farmers on the use of breeding substrates for cocoa pollinators, descriptive statistics, the weighted mean was employed. This method provides a comprehensive summary of the farmers' perceptions, capturing both central tendencies and variations within the data. Descriptive statistics are pivotal in a quantitative study (Perera et al., 2022). For this study, the descriptive statistics offered insights into the cocoa farmers' perception towards pollinator technology. The weighted mean is particularly useful when different data points contribute varying levels of importance to the overall average (Lu et al., 2022). The calculation involved multiplying each data point by a pre-assigned weight based on the perceived importance of the factors. The sum of the products was calculated and divided by the sum of the weights. In this study, survey responses related to farmers' perceptions on pollinator technology were collected using a structured questionnaire.

Likert scale was used to assess each response. The Likert scale was categorized into five (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agreed, 5 = strongly agree). Responses were weighted based on their frequency or importance. The steps involved in this analysis included administering the structured questionnaire to a representative sample of cocoa farmers, assigning appropriate weights to responses based on their frequency or perceived importance. The weighted mean was then calculated by multiplying each response by its assigned weight, sum their products, and divide by the sum of the weights. Finally, the results were interpreted by analyzing the weighted means to draw conclusions about the overall perception levels among cocoa farmers. Using the weighted mean ensured that the analysis captures the significance of different responses, leading to more accurate and meaningful insights into the farmers' perceptions. The model specification is presented as;

$$\bar{X}_{Wt} = \frac{\sum_{n=1}^{i} w_i X_i}{\sum_{n=1}^{i} w_i} \quad \ldots\ldots (1)$$

where $\bar{X}_{Wt}$ is the weighted mean, X_i represents the individual data points, and W_i is the weights assigned to each data point. Cronbach alpha was used to test for the overall adequacy of the data for the Likert scale.

3.5.2 Analyzing the factors influencing pollinator technology adoption among cocoa farmers

To identity the factors influencing pollinator technology adoption binary logistic regression model was used with marginal effects to interpret the effects of independent variables on the likelihood of adopting the technology. The binary logistic regression model was appropriate for examining the relationship between a binary dependent variable and a set of independent variables. The dependent variable is the adoption of pollinator technology by cocoa farmers, coded as '1' if the farmer has adopted the technology and '0' if otherwise. The usage of this model yields the best likelihood estimation as compared to using the linear probability model, Probit model, or the interval regression model. According to Kwadzo et al. (2013), logit model yields asymptotically consistent, efficient and estimates the regression test to be used. The binary logit regression model is estimated as:

$$\log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_i x_i + U_i \quad \ldots\ldots (2)$$

Equation (2) is modeled to give equation (3)

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 AGEi + \beta_2 EDUi + \beta_3 GNDi + \beta_4 HSZi + \beta_5 AEAi + \beta_6 TRNi + \beta_7 LABi + \beta_8 NLNi + \beta_9 OFINi + \beta_{10} ONFINi + \beta_{11} FBOi + \beta_{12} CRDTi + \varepsilon_i \quad \ldots\ldots (3)$$

where,

$\ln\left(\frac{p}{1-p}\right)$ is the log odds ratio,

P represents the probability that a cocoa farmer adopts pollinator technology,

$1 - p$ represents the probability that a cocoa farmer does not adopt pollinator technology,

β_0 is the intercept of the model,

$\beta_1, \ldots \beta_{13}$ are the coefficients of the independent variables (AGE, EDU, GND, etc.) and

ε_i is the error term.

Hypothesis: To evaluate the significance of each independent variable, hypothesis tests were conducted.

Null Hypothesis (H_0): The factor that influence adoption of pollinator technology (age, education, gender etc.) do not significantly affect the likelihood of adopting pollinator technology.

Alternative Hypothesis (H_1): The factor that influence adoption of pollinator technology (age, education, gender etc.) significantly affects the likelihood of adopting pollinator technology.

The null hypothesis was tested for each variable using t-test, while the joint significance of all the variables were tested using the F-test.

Validation of Hypothesis

The individual significance was validated using the t-test at 5% level of significance. The test statistic is calculated as follows:

$$T - cal = \frac{\beta i - 0}{SE(\beta)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

β_i = estimated parameter and SE= standard error of the regressor

The decision rule is that the variables with a t-calculated value greater than the critical value at a 5% significance level is considered as statistically significant.

Model Specification for Marginal Effects

After estimating the binary logistic regression model, marginal effects were calculated to interpret the effects of each independent variable on the probability of adopting pollinator technology among the cocoa farmers. The marginal effect measures the change in the probability of adoption for a one-unit change in an independent variable, holding all other variables constant (Remiro-Azócar, 2022). For continuous independent variables (age, years of farming experience, farm size) the marginal effect is calculated as:

Marginal Effect = $\frac{\partial \boldsymbol{P(Y=1)}}{\partial Xi} = P(Y = 1) \times (1 - P(Y = 1)) \times \beta_i$............................ (5)

P(Y=1) is the predicted probability of adopting pollinator technology,

β_i is the estimated coefficient for the continuous independent variable Xi.

The marginal effect indicates how the probability of adopting pollinator technology changes with a small change in the continuous variable X_i. For categorical independent variables (gender, marital status), the marginal effect is calculated as the discrete change in the probability of adoption when the variable changes from one category to another (i.e., from.0 to 1)

Marginal Effect = P(Y = 1 | Xi = 1) – P(Y = 1 | Xi = 0)............................ (6)

This represents the difference in the predicted probability of adopting pollinator technology when the categorical variable Xi changes from 0 (reference category) to 1. The average marginal effect is also calculated to provide a summary measure of the impact of each independent variable across all observations. The average marginal effect is the average of the individual marginal effects for all observations in the dataset:

AME = $\frac{1}{N}\sum_{i=1}^{N}\frac{\partial P(Y=1)}{\partial Xi}$.. (7)

Where: N is the number of observations, and $\frac{\partial P(Y=1)}{\partial Xi}$ represents the marginal effect for observation i.

The marginal effects provide more intuitive understanding of the results from the logistic regression model, making it easier to convey the effects of different factors that influence adoption decision of the cocoa farmers.

Explanation of variables

AGE: This variable represents the age of the farmers. It is expected that younger farmers would be more inclined to adopt pollinator technology, as they are prone to be more innovative and open to new agricultural practices.

GEN: This variable represents the gender of the respondents where 1 denotes males and 0 denotes females. Males are often more likely to adopt pollinator technology, possibly due to better access to information and resources. In addition, males are found to participate in agricultural activities than females (Mbam & Nwibo, 2013) a positive relationship with the adoption decision is expected.

EDU: The variable indicates educational level of the farmers. Farmers with some degree of formal education are expected to be more likely to adopt pollinator technology, as education often enhances understanding and openness to new technologies.

HSZ: This variable denotes the size of a farmer's household. Farmers with larger household sizes are anticipated to be more inclined to adopt pollinator technology, as the pressure to secure higher yields to support their families may drive them to seek innovative farming solutions.

CRDT: This variable indicates the farmer's access to credit. It is postulated that farmers with access to credit are more likely to adopt pollinator technology, as they may have the financial resources to invest in such technologies.

NLN: This variable specifies the type of land ownership. It is computed using a dummy variable, with 1 representing ownership of the land and 0 representing not land owner. Farmers who own their land are expected to be more willing to adopt pollinator technology, as land ownership may enhance their ability to invest in long-term productivity.

FBO: This variable represents the farmer's membership in a Farmer-Based Organization. It is measured as a dummy variable, with 1 indicating that the farmer is a member of an FBO and 0 indicating non-membership. Membership in an FBO is expected to positively influence the adoption of pollinator technology. FBOs often provide access to resources, information, and support that can encourage farmers to adopt innovative practices.

LAB: This variable is the type of labour employed by the farmers on their farm. It is a dummy variable where 1 represent hired labour and 0 represnt family labour. Hired labour could more efficient but costly, while family labour could be cheaper and less costly.

AEAS: This variable indicates farmers' access to agricultural extension services. It is measured as a dummy variable, where 1 indicates farmers' access to AEAS and 0 indicates no access by farmers to AEAS. Access to AEAS is expected to positively influence the adoption of pollinator technology, as extension services provide farmers with knowledge, training, and technical support that can facilitate the adoption of new agricultural technologies.

TRN: This variable indicates the training received by cocoa farmers on pollinator technology. It is expected that farmers that take part in training programmes will have greater technological uptake and understanding than farmers that do not.

The explanatory variables or factors considered are presented in Table 3.1.

Table 3.1: Description of variables

Variable	Description	Measurement	Expectation
AGE	Age of respondent	Years	+/-
GEN	Gender	Dummy (1= male, 0	+/-

		=female)	
EDU	Educational level	Years	+
HSZ	Household size	Number	-
CRDT	Access to credit	Dummy (1= yes, 0 = no)	+/-
NLN	Nature of land holding	Dummy (1 = purchased, 0 =hired)	+
FBO	FBO Membership	Dummy (1= yes, 0 = no)	+
LAB	Type of labour	Dummy (1 = hired, 0 = family)	+
AEAs	Access to extension agents	Dummy (1 = yes, 0 = no)	+/-
TRN	Training	Dummy (1 = yes, 0 = no)	+/-

Source: Field survey, 2024

3.5.3 Examining the impact of pollinator technology on cocoa productivity

Impact evaluation involves assessing the impacts of an intervention or treatment to determine its causal impact (Fröhlich et al., 2019). Several methods including randomized controlled trials, difference-in-differences, propensity score matching and regression discontinuity design are commonly used for impact evaluation, each with its strengths and limitations (Popovic et al. 2024; Fredriksson & Oliveira, 2019; Dixit et al., 2018). The Inverse Probability Weighted Regression Adjustment (IPWRA) was used to assess the impact of pollinator technology on cocoa productivity. IPWRA balances covariates by using inverse probability weighting to generate synthetic sample where the distribution of covariates is independent of treatment assignment thereby reducing bias due to confounders. By combining weighting with regression adjustment, IPWRA produces efficient estimates of treatment effects, as the regression adjustment reduces residual variance, leading to more precise estimates (Uysal & Wooldridge, 2022). Moreover, IPWRA is a doubly robust estimator. This means that it remains consistent if either the model for the treatment assignment or the model for the outcome is correctly specified, enhancing the credibility of the estimates. It effectively handles confounders by explicitly modeling both the treatment assignment and the outcome, offering better control for observed confounders (Shin & Antonelli, 2023). Additionally, IPWRA is versatile and can be applied in observational studies where randomization is not possible and clear cutoffs do not exist, making it a flexible tool for impact evaluation across different contexts and settings (Uysal & Wooldridge, 2022). The treatment model is specified as:

$$\ln\left(\frac{P(ADOPT_i = 1|Xi)}{1-P(ADOPT_i = 1|Xi)}\right) = \beta_0+\beta_0+\beta_1 AGEi + \beta_2 EDUi + \beta_3 GNDi + \beta_4 HSZi + \beta_5 AEAi + \beta_6 TRNi + \beta_7 LABi + \beta_8 NLNi + \beta_9 OFINi + \beta_{10} ONFINi + \beta_{11} FBOi + \beta_{12} CRDTi + \mathcal{E}_i \quad (8)$$

Where: $ADOPT_i$ is a binary variable indicating adoption of pollinator technology (1 for adoption, 0 for non-adoption),

X_i represents the covariates,

β_j are the coefficients for the covariates and

$\mathcal{E}_i$ is the error term.

Calculation of Inverse Probability Weights

The probabilities estimated from the treatment model were calculated for the inverse probability weights as;

$$W_t = \left(\frac{1}{P(ADOPT_i = 1|Xi)}\right) \quad (9)$$

where $P(ADOPT_i = 1 \mid X_i$ is the estimated probability of adopting pollinator technology for the i^{th} observation, meaning cocoa farmer.

The outcome model is then specified to estimate the effect of pollinator technology adoption on cocoa productivity, using the inverse probability weights from the equation 9.

The model is specified as: $Y_i = \gamma_0 + \gamma_1 ADOPT_i + \gamma_2 X_i + \epsilon_i$ .... (10)

where:

Y_i is the productivity outcome for the i^{th} farmer,

γ_0 is the intercept,

$ADOPT_i$ indicates whether the farmer adopted pollinator technology,

X_i includes other covariates related to productivity,

γ_i is the coefficient for the adoption variable, representing the impact of adopting pollinator technology on productivity,

ϵ_i is the error term.

The regression is weighted by the inverse probability weights (w_t)to correct for any selection bias in the treatment assignment. To assess the impact of pollinator technology adoption on cocoa productivity, the Average Treatment Effect on the Treated (ATET) and the Average Treatment Effect (ATE) were calculated. These measures help quantify the effect of adopting pollinator technology on cocoa productivity. The ATET measures the expected difference in outcomes for those who received the treatment (adopted pollinator technology) compared to what their outcomes would have been if they had not received the treatment.

In practice, the ATET is estimated as:

$$ATET = E(Y_t \mid ADOPT_i = 1) - E(Y_0 \mid ADOPT_i = 1) \quad \text{.................................. (11)}$$

where,

$E(Y_t \mid ADOPT_i = 1)$ is the average productivity of farmers who adopted pollinator technology and $E(Y_0 \mid ADOPT_i = 1)$ is the expected counterfactual productivity for the same group if they had not adopted pollinator technology. This is typically estimated using the outcome model adjusted by the inverse probability weights. The ATE measures the effect of the treatment (pollinator technology adoption) on the entire population, comparing those who adopted the treatment with those who did not.

ATE is estimated as: $ATE = E(Y_t \mid ADOPT_i = 1) - E(Y_0 \mid ADOPT_i = 0)$......... (12)

$E(Y_t \mid ADOPT_i = 1)$ is the average productivity of farmers who adopted pollinator technology and $E(Y_0 \mid ADOPT_i = 0)$ is the expected productivity of farmers who did not adopt pollinator technology, estimated using the outcome model with appropriate adjustments.

To ensure the validity and reliability of estimated treatments effect by using the Inverse Probability Weighting with Regression Adjustment (IPWRA) method, several diagnostic tests were performed. First, a balance test was conducted to verify that the covariates are balanced across the treatment and control groups after applying the inverse probability weights. The Standardized Mean Difference (SMD) was calculated for each covariate before and after weighting, with the expectation that the SMD will be close to zero post-weighting, indicating good balance. Next, an over identification test was performed to assess the validity of the instruments used in the model. This test was to check whether the instruments are uncorrelated with the error terms in the outcome model. This is necessary for the consistency of the estimates. A non-significant p-value from this test will suggest that the instruments are valid and the model has been properly specified. Additionally, overall fit and specification of the model was evaluated using various diagnostic measures. These include the log-likelihood, pseudo-R-squared, and the Hosmer-Lemeshow test, which assessed the adequacy of the logistic regression model used for predicting treatment assignment. Finally, robustness checks such as the over-identification test were conducted to ensure that the results are not sensitive to specific model choices or assumptions. These diagnostic tests were critical in validating that the estimated impact of pollinator technology adoption on cocoa productivity is credible and well-supported by the data. The variables used for the regression are presented in Table 3.2

Table 3.2: Summary of variables used in the regression

Variable	Description of variable	Measurement
Outcome variable		
Productivity	Yield	Output per hectare (kg/ha)
Treatment Variable		
X_1	Adoption of Pollinator Technology	Dummy (1=adopted 0=no adoption)
Explanatory variables		
Age	Age in years	Years
Labour	Type of labour	(Dummy 1=Hired 0=family)
Gender	Sex of farmer	Dummy (1=Male, 0=Female)
Education	Years of formal education	Years
Credit	Access to credit	Dummy (1 =yes 0 = no)
Training	Farmer has acquired training on Pollinator Technology	Dummy (1=yes 0=no)
Off-farm income	Engages in off-farm income-generating activities	Ghana cedis per year
AEAs	Access to Agricultural extension services	Dummy (1=yes 0=no)
FBO	Member of farmer-based organization	Dummy (1=yes 0=no)
NLN	Nature of land holding	Dummy (1 = purchased 0 = hired)
Household size	Number of people in the household	Number

Source: Field survey 2024

3.5.4 Identifying and ranking the constraints to pollinator technology adoption among cocoa farmers

To identify and rank the constraints encounter by cocoa farmers adopting pollinator technology in the Osino cocoa district, farmers were asked to rank the constraints they encounter using a scale of 1 to 8, where 1 represents the most pressing constraint, and 8 represents the least pressing constraint. The total rank for each constraint was computed by summing the ranks assigned by all respondents. The constraint with the lowest total score was identified as the most pressing, while the one with the highest total score was identified as the least pressing. To test for the agreement among the farmers' rankings of these constraints, Kendall's coefficient of concordance (W) was employed. This non-parametric statistical method is used to estimate the strength and consistency of associations among rankings made by different individuals. Kendall's coefficient is preferred over other correlation measures, such as Spearman's correlation, because it is generally more robust and efficient in cases where rankings are involved (Shiekh & El-Hashash, 2022; Puth et al. 2015)

The coefficient of concordance (W) was calculated using the formula:

$$W = \frac{n\left[T^2 - \frac{(\sum T^2)}{n}\right]}{mn^2(n^2-1)} \quad \text{......} (13)$$

where,

W estimates the proportion observed variance of the sum of ranks and the maximum possible variance of the sum of ranks,

T denotes the sum of ranks for the factors ranked,

m = number of respondents, and

n = number of factors ranked.

The maximum variance (T) is specified as:

$$T = \frac{m^2(n^2-1)}{5} \quad \ldots\ldots (14)$$

$$Var\ T = \left[\sum T^2 - \frac{(\sum T)^2}{n}\right] \quad \ldots\ldots (15)$$

The coefficient of concordance (W), used to measure the level of agreement, is determined by the based on the total rank score. The values of W are specified as $0 \leq W \geq 1$, where 1 represents complete agreement among the respondents, and 0 indicate complete disagreement.

To test the statistical significance of the W, the Chi-square (x^2) was expressed as;

$$x^2 = \gamma(n^2 - 1)W \Big/ (k + 1) \quad \ldots\ldots (16)$$

where

$n - 1$ represents the degrees of freedom,

k represents number of causes presented at a time, and

γ represents the number of times a given comparison occurs

The following hypotheses are assumed;

H_0: There is no agreement on the constraints to the adoption of pollinator technology among cocoa farmers in the Osino cocoa district.

H_A: There is agreement on the constraints to the adoption of pollinator technology among cocoa farmers in the Osino cocoa district.

The decision rule is if the Chi-square (x^2) calculated is greater than the critical x^2, the null hypothesis is rejected, and it can be concluded that there is agreement among the constraints.

3.6 Study population

According to Babbie (2020), population is the total aggregate respondents. In this study the population includes all cocoa farmers in the study area. The population of cocoa farmers in the study area is estimated at 35000 (Cocoa Management System, 2022).

3.7 Source of data

The study employed primary data as the main source of data. The research objective guided the design of the data collection instrument. The structured questionnaire was used to elicit primary information from the cocoa farmers. The questionnaires were divided into five sections to elicit information. Section A, addressed farmer characteristics which included socio-economic and institutional support characteristics. Section B focused on the farm characteristics. It addressed questions on farm size, number of farms and pollinator technology. Sections C had questions on perception of coca farmers on pollinator technology. Section D of the questionnaire is on the impact of pollinator technology among cocoa farmers, while section E addressed the constraints to pollinator technology among cocoa farmers.

3.8 Data collection

The questionnaires were administered in-person through interviewing the selected respondents in the study area. Trained cocoa extension agents interpreted the questions to the farmers in the local dialect and filled out the questionnaire. The use of local dialect in combination with the cocoa extension agents provided timely clarification relating to the technical terms to preserve the accuracy of the responses from the questionnaires. Data collection was conducted in adherence to ethical guidelines, ensuring informed consent, and confidentiality.

3.9 Sampling Procedure and Sample Size

The study employed a multistage sampling procedure to select 400 respondents from the Osino cocoa district in Eastern region of Ghana. The multistage sampling process was designed to ensure a representative sample of smallholder cocoa farmers who have adopted or are potential adopters of pollinator technology. In the first stage, the Osino cocoa district in the Eastern region was purposively selected due to its significant contribution to cocoa production in Ghana and the presence of ongoing initiatives promoting agricultural technology adoption. Eastern Region is currently the second after Western Region in terms of cocoa production in Ghana and the first point of cocoa introduction in 1879 (Okali, 2013). The Eastern region of Ghana contributes about 19% of the country's total cocoa production, making it a significant cocoa producing area accounting (Yahaya, Karli, and Gül, 2015). The Osino cocoa district comprises of the Atiwa and Fanteakwa administrative districts. In the second stage, a list of cocoa farmers was obtained from the district cocoa office. These farmers were stratified based on their level of engagement in pollinator technology interventions, ensuring that both adopters and non-adopters were included. From these strata, a simple random sampling method was used to select the farmers to be included in the study. Hossan et al, (2023) defined sample size as individual subsets drawn from a population. The Yamane formula was used to determine the sample size.

$$\boldsymbol{n} = \frac{N}{1+N(e)^2} \qquad \text{.......... (17)}$$

where n is the sample size from the population, N is the cocoa farmers under study, and e represent the sampling error (0.05).

$$\boldsymbol{n} = \frac{24376}{1+35000(0.05)^2} = \mathbf{393}$$

The initial calculation determined a sample size of 393 participants. However, to simplify the study's implementation and improve generalizability, the sample size was increased to 400. This adjustment ensures robustness by accounting for potential non-responses and aligns with the standard practices of rounding sample sizes to practical and manageable figures (Dillman et al., 2014; Kotrlik, & Higgins, 2001)

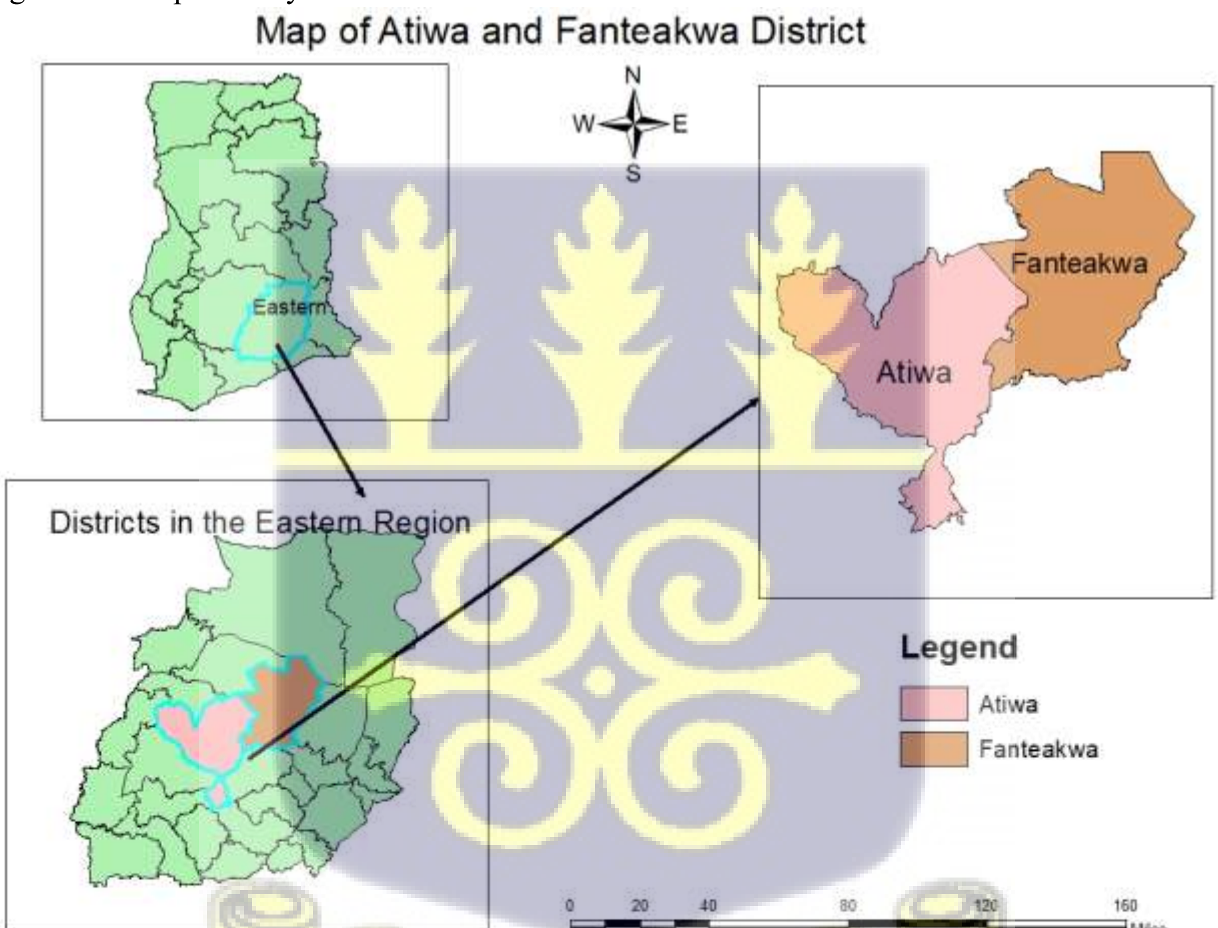
3.10 Study area

The Osino cocoa district is situated within the Fanteakwa and Atiwa administrative districts. The Fanteakwa district is situated centrally within Ghana's Eastern region. It shares borders with Atiwa districts to the south, Kwahu Afram Plains South district to the north, East Akim and Upper Manya and Yilo Krobo districts to the east and Kwahu South district to the northwest. Covering an area of approximately 1,150 square kilometers, it ranks as the third-largest district in the region in terms of land size. The district records an average annual temperature of 24°C and is characterized by a generally cool and humid climate throughout the year. Predominantly, the area consists of forest zones, with a few semi-savannah regions in the north. About 80% of the district is covered by wet semi-deciduous forest, which is well-suited for cultivating cash and staple crops such as cocoa, oil palm, coffee, citrus, and rubber, maize, plantain, rice, cocoyam, and vegetables (Ghana Statistical Service (GSS, 2014).

The Atiwa district is bordered by Kwaebibirem district to the south, Fanteakwa district to the northeast, Birim North district to the west Kwahu West and Kwahu South districts to the north, and East Akim district to the southeast. Temperatures in the district range from 26°C to 30°C, and relative humidity levels vary from 65-75% during the dry season to 75-80% in the rainy season. With a land area of about 1,165.3 square kilometers, it lies within the wet semi-equatorial zone, characterized by a bi-modal rainfall pattern. The Atiwa district is part of the moist semi-deciduous forest zone, featuring reddish-brown, well-drained soils on elevated lands (Ghana Statistical Service (GSS, 2014).

Cocoa farming remains a primary source of income for households in the Atiwa and Fanteakwa districts with over 70% of households in the districts depending on cocoa farming as their main livelihood activity. Production in Atiwa is estimated at 4,000-6,000 metric tonnes annually, while that of Fanteakwa is estimated at 3,000-5,000 metric tonnes annually (COCOBOD, 2023).

Figure 3.2: Map of study area



Source: Field survey, 2024

3.11 Limitations of the Study

This study has some limitations that should be acknowledged. The study employed a quantitative quasi-experimental design without incorporating qualitative methods such as focus group discussions or key informant interviews. This was due to time and resource constraints, as well as the wide geographic spread of respondents. Consequently, the study could not capture in-depth insights into farmers' perceptions and contextual factors influencing pollinator technology adoption. In addition, the use of cross-sectional data limits the ability to establish definitive causal relationships, as adoption behaviour and productivity outcomes may vary over time. Although the data were carefully collected, self-reported responses may also be affected by recall or social desirability bias.

Despite these limitations, the study provides useful empirical evidence on the determinants and productivity effects of pollinator technology adoption and serves as a foundation for future research that integrates qualitative data.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the key results from the study on the impact of pollinator technology on cocoa productivity among smallholder farmers in the Osino cocoa district.

4.2 The socio-economic characteristics of the respondents

Table 4.1 presents the results of the t-test comparing the socio-economic characteristics of adopters and non-adopters of the production technology. The variables considered were yield, age, farming experience, household size, total farm size, and income. The results show that adopters recorded a higher average yield (696.17 kg) compared to non-adopters (297.47 kg). The mean difference of 398.70 is statistically significant at the 1% level ($p < 0.01$). This indicates that farmers who adopted the technology obtained substantially higher yields than those who did not. Similarly, income was significantly higher among adopters (GH₵ 8,702.12/year) compared to non-adopters (GH₵ 3,718.39/year). The mean difference of GH₵ 4,983.72/year is also significant at the 1% level ($p < 0.01$). This suggests that adoption of the production technology had a positive effect on farmers' income, likely due to increased productivity and efficiency. The farming experience of adopters (17.34 years) was slightly higher than that of non-adopters (16.08 years), with a mean difference of 1.27, significant at the 5% level ($p = 0.0271$). This implies that more experienced farmers are more likely to adopt the technology compared to less experienced ones.

Table 4.1: Summary of quantitative variables

Variable	Mean (Adoption)	Mean (No Adopted)	Mean Difference	t-value	p-value
Yield (kg)	696.17	297.47	398.70	14.87	0.0000***
Age (years)	49.22	47.88	1.34	1.19	0.2358
Experience (years)	17.34	16.08	1.27	2.22	0.0271*
Household size	4.23	4.49	-0.26	-1.31	0.1913
Farm size (acres)	3.59	3.48	0.11	0.34	0.7353
Income (GH₵)	8,702.12	3,718.39	4,983.72	14.87	0.0000***

Source: Field survey, 2024

However, age, household size, and farm size showed no statistically significant differences between adopters and non-adopters. The mean age was 49.22 years for adopters and 47.88 years for non-adopters ($p = 0.2358$), indicating that age did not play a major role in adoption. The mean household sizes were 4.23 and 4.49 respectively ($p = 0.1913$), suggesting similar household size among both groups. Farm sizes were also comparable, with averages of 3.59 acres for adopters and 3.48 acres for non-adopters ($p = 0.7353$).

From Table 4.2, the results showed the socio-demographic characteristics of respondents and their association with the adoption of cocoa pollination technology. The results indicate that 80.78% of non-adopters and 80.69% of adopters were males, while 19.22% and 19.31%, respectively, were females. This suggests that cocoa farming in the study area remains a predominantly male-dominated activity, with no significant difference ($\chi^2 = 0.0005$; $p = 0.982$) between males and females regarding adoption of the technology.

The educational level of respondents showed that among non-adopters, 49.41% had no formal education, compared to 47.59% among adopters. Similarly, 23.92% of non-adopters and 26.90% of adopters had attained junior high school education, while 15.69% and 13.10% had completed senior high school education, respectively. Only 0.78% of non-adopters and 3.45% of adopters had attained tertiary education. Although a relatively higher proportion of adopters had some form of formal education, the Chi-square test ($\chi^2 = 4.701$; $p = 0.319$) indicates that the difference in educational attainment between adopters and non-adopters was not statistically significant. In terms of marital status, 81.57% of non-adopters and 77.24% of adopters were married, followed by 7.84% and 8.97% who were single, 5.88% and 5.52% divorced, and 4.71% and 8.28% widowed, respectively. However, the difference between adopters and non-adopters was not statistically significant ($\chi^2 = 2.342$; $p = 0.504$).

Regarding religion, 90.59% of non-adopters and 92.41% of adopters identified as Christians, while 9.41% and 7.59%, respectively, were Muslims. The dominance of Christianity reflects the religious composition of the study area and suggests no notable influence of religious affiliation on technology adoption ($\chi^2 = 0.386$; $p = 0.534$). With respect to land ownership, most respondents in both groups accessed farmland through family inheritance (43.92% of non-adopters and 44.83% of adopters) or shared cropping arrangements (41.57% and 37.93%, respectively). A smaller proportion acquired land through purchase (9.02% vs. 11.72%) or lease/rent (5.49% vs. 5.52%). The Chi-square result ($\chi^2 = 0.997$; $p = 0.802$) indicates no significant relationship between land tenure system and adoption status, suggesting that ownership structure did not influence the decision to adopt pollination technology.

Membership in FBOs was generally high among both adopters (83.45%) and non-adopters (80.39%). The difference was statistically insignificant ($\chi^2 = 0.573$; $p = 0.449$), but the relatively higher participation among adopters implies that group membership may facilitate information sharing and collective learning about new technologies. Access to Agricultural Extension Agents (AEAs) was reported by 62.30% of non-adopters and 61.11% of adopters, while 37.70% and

38.89%, respectively, and had no access. The Chi-square result ($\chi^2 = 0.055$; $p = 0.814$) confirms that there was no significant difference between the two groups. This suggests that while extension services are crucial for technology dissemination, mere access alone may not determine adoption unless accompanied by effective engagement and follow-up.

The results from the chi-square tests across all socio-demographic variables revealed no statistically significant association ($p > 0.05$) between farmers' demographic characteristics and their adoption of cocoa pollination technology. This implies that gender, education, marital status, religion, land ownership, FBO membership, and access to AEAs did not significantly influence adoption decisions within the study area. However, descriptive patterns suggest that respondents with some level of education and those involved in FBOs exhibited a relatively higher tendency toward adoption, indicating potential areas for policy and extension emphasis.

Table 4.2: Summary of categorical variables

Variable	Category	No Adoption		Adopted		Total		Chi-square (p value)
		Freq.	**%**	**Freq.**	**%**	**Freq.**	**%**	
Gender	Female	49	19.22	28	19.31	77	19.25	0.0005 (0.982)
	Male	206	80.78	117	80.69	323	80.75	
Education	None	126	49.41	69	47.59	195	48.75	4.701 (0.319)
	JHS	61	23.92	39	26.90	100	25.00	
	Primary	26	10.20	13	8.97	39	9.75	
	SHS	40	15.69	19	13.10	59	14.75	
	Tertiary	2	0.78	5	3.45	7	1.75	
Marital Status	Married	208	81.57	112	77.24	320	80.00	2.342 (0.504)
	Divorced	15	5.88	8	5.52	23	5.75	
	Single	20	7.84	13	8.97	33	8.25	
	Widowed	12	4.71	12	8.28	24	6.00	
Religion	Christian	231	90.59	134	92.41	365	91.25	0.386 (0.534)
	Islam	24	9.41	11	7.59	35	8.75	

Land Ownership	Family	112	43.92	65	44.83	177	44.25	0.997 (0.802)
	Lease/Rent	14	5.49	8	5.52	22	5.50	
	Purchased	23	9.02	17	11.72	40	10.00	
	Shared Cropping	106	41.57	55	37.93	161	40.25	
FBO Membership	No	50	19.61	24	16.55	74	18.50	0.573 (0.449)
	Yes	205	80.39	121	83.45	326	81.50	
Access to AEAs	No	95	37.70	56	38.89	151	37.75	0.055 (0.814)
	Yes	157	62.30	88	61.11	245	62.25	

Source: Field survey, 2024

4.3 Adoption of pollinator technology by respondents

The results presented in Table 4.3 indicate that the adoption of pollinator technology among respondents is relatively low, with 52.5% of respondents indicating that they have not adopted the technology, compared to 47.5% who have adopted the pollinator technology. The finding that more than half of the respondents have not adopted pollinator technology highlights the need for further investigation into the barriers and challenges that hinders the adoption of the technology. These could include factors such as limited access to resources, lack of knowledge or training, perceived complexity, or concerns about the effectiveness and benefits of the technology. Studies indicate that although a large number of people indicate a desire to participate in these activities, actual adoption is still low because of perceived complexity and pests and disease concerns (Silvert et al., 2023; Warner, et al., 2023). Conversely, the respondents who have adopted the technology indicate that there is a substantial group of farmers who recognize its potential benefits, such as improved yields or reduced environmental impact (Frimpong Anin & Kwapong, 2020; Adjaloo et al., 2017).

Table 4.3: Adoption of pollinator technology

Gender	Frequency	Percent
Non-adopters	210	52.5
Adopters	190	47.5
Total	**400**	**100**

Source: Field survey, 2024

4.4 Cocoa farmer's perception about pollinator technology

The weighted mean index (WMI) of 3.44 was used as a benchmark to interpret farmers' perceptions of pollinator technology. As a decision rule a statement above WMI 3.44 were interpreted as reflecting a positive perception, indicating that farmers held favorable attitudes towards the benefits of the technology. Conversely, a statement with a WMI below 3.44 signified a negative perception, highlighting concerns or challenges associated with the technology. A WMI equal to 3.44 was considered neutral, meaning that the farmers neither agreed nor disagreed with the statement. This approach provided a clear framework for understanding the overall perception of farmers towards pollinator technology. Table 4.4 presents the perceptions of cocoa farmers on pollinator technology. A majority of farmers, specifically 81.8%, strongly agree that pollinator technology enhances soil nutrients, as indicated by a mean score of 4.8 and a standard deviation of 0.449. The high level of agreement indicates that farmers acknowledge the positive influence of pollinator technology on soil health. This could mean that the farming community widely acknowledges the beneficial effects of pollinator technology on soil health. The mean score which is close to the maximum value of 5 reflects a strong consensus that pollinator technology significantly contributes to improving soil nutrient levels. The relatively low standard deviation further underscores the uniformity of this positive perception among farmers, suggesting that most respondents share a similar viewpoint regarding the benefits of this technology. Enhanced soil nutrients are crucial for sustainable agriculture as they contribute to better crop growth and yield (Saha & Bauddh, 2020). This positive perception of pollinator technology's impact on soil health could be attributed to the observed benefits such as improved soil fertility, improved organic matter, and better nutrient cycling, all of which are essential for maintaining productive and sustainable cocoa farming practices (Wongnaa et al, 2022).

Table 4.4: Perception of cocoa farmers about pollinator technology

	SA (%)	A (%)	N (%)	D (%)	SD (%)	Mean	σ	Decision
Leads to improved soil nutrients	327 (81.8)	65 (16.3)	8 (2)	0 (0)	0 (0)	4.8	0.449	Positive
It is simple and easy to practice	317 (79.3)	68 (17)	15 (3.8)	0 (0)	0 (0)	4.76	0.511	Positive
Improves cocoa yields	319 (79.8)	57 (14.2)	24 (6)	0 (0)	0 (0)	4.74	0.561	Positive
It makes weeding on the cocoa farm difficult	0 (0)	22 (5.5)	60 (15)	273 (68.3)	45 (11.3)	2.15	0.68	Negative
Increases cost of agro-chemicals inputs	0 (0)	26 (6.5)	59 (14.8)	268 (67)	47 (011.8)	2.16	0.708	Negative
Increases cost of farm labour	0 (0)	21 (5.3)	61 (15.3)	280 (70)	38 (9.5)	2.16	0.657	Negative
Increases the incidence of pests and diseases	4 (1)	91 (22.8)	64 (16)	177 (44.2)	64 (16)	2.49	1.043	Negative
Reduces toxicity and residue in the environment	120 (30)	255 (63.7)	17 (4.3)	8 (2)	0 (0)	4.22	0.613	Positive

N = 400 WMI= 3.44. Cronbach alpha 0.78

Source: Field survey, 2024

The farmers' strong agreement highlights the perceived value of integrating pollinator technology into their cocoa farming activities, reinforces its role as a beneficial tool for enhancing soil quality and supporting overall farm productivity. Furthermore, 79.8% of respondents also agree that pollinator technology improves cocoa yields, with a mean score of 4.74 and a standard deviation of 0.561. This high level of agreement underscores the farmers' confidence in the technology's ability to enhance productivity. The strong positive perception is indicative of the widespread belief among cocoa farmers that the implementation of pollinator technology can lead to significant increases in cocoa yield. The high mean score reflects a collective endorsement of the technology's effectiveness in boosting production, while the standard deviation, though slightly higher, suggests that while most farmers view the technology favorably, there are some variation in individual opinions. This variability could be attributed to differences in local conditions, farm management practices, or personal experiences with the technology. Overall, the consensus on yield improvement highlights the perceived practical value of pollinator technology in enhancing agricultural outputs, suggesting that its adoption could lead to substantial productivity gains in cocoa farming.

Again, it is observed from the results in Table 4.4 that 79.3% of respondents view pollinator technology as simple and easy to practice, as evidenced by a mean score of 4.76 and a standard deviation of 0.511. This strong positive perception suggests that a significant proportion of farmers find the technology not only accessible but also user-friendly. The high mean score indicates that most farmers appreciate the simplicity and ease of use associated with pollinator technology, which could contribute to its adoption. The relatively low standard deviation further reflects a consensus among farmers regarding the ease of implementation, suggesting minimal variation in their views. This positive assessment of usability highlights that pollinator technology is perceived as a practical solution that can be readily integrated into existing farming practices, potentially facilitating its broader acceptance and application in cocoa cultivation. The ease of use is a crucial factor in the successful adoption of new agricultural technologies, as it reduces the barriers to implementation and encourages farmers to incorporate innovative practices into their operations (Asirifi, et al., 2024). Also, a significant majority, (68.3%) of farmers, disagree with the notion that the technology complicates weeding, as reflected by a mean score of 2.15 and a standard deviation of 0.68. This indicates that, contrary to potential concerns, a substantial proportion of farmers do not perceive pollinator technology as an impediment to their weeding activities. The low mean score suggests that, on average, farmers do not view the technology as increasing the difficulty of weeding tasks. The relatively low standard deviation shows there is some consistency in the perception of pollinator technology among the farmers. This finding is important as it addresses a potential barrier to technology adoption, highlighting that, farmers generally do not find pollinator technology to adversely affect their weeding processes. The perception of minimal impact on weeding may contribute to a more favorable view of the technology, supporting its continued use and adoption in cocoa farming (Wongnaa, et al., 2022).

Furthermore, the technology is perceived not to increase the cost of farm labour, with a substantial majority 70% of respondents disagreeing with the notion that it raises labour expenses. This sentiment is reflected in a mean score of 2.16 and a standard deviation of 0.657, indicating that most farmers do not perceive pollinator technology as a factor contributing to high labour cost. This suggests that, contrary to potential concerns, the implementation of pollinator technology is not associated with significant additional expenses related to labour (Debeuckelaere et al., 2024). The standard deviation, which reflects the variability in responses, is relatively low, indicating a consensus among the respondents. This uniformity in opinion reinforces the view that, overall, farmers do not perceive pollinator technology as a burden that increases labour costs. The absence of a substantial negative impact on labour expenses could be a crucial factor in the positive reception of the technology among cocoa farmers (Dormon et al., 2004).

Additionally, 44.2% of farmers disagreed that pollinator technology exacerbates pest and disease issues, as evidenced by a mean score of 2.49 and a standard deviation of 1.043. There is a knowledge gap on the effects of pesticide use on pollinators (Umeh et al., 2022). This indicates a divided opinion among the respondents, with nearly half expressing concern that the use of pollinator technology may contribute to increased pest and disease challenges on their farms. The relatively higher standard deviation suggests variability in the farmers' perceptions, reflecting differing experiences or levels of understanding regarding the impact of the technology on pest and disease management. On a positive note, 63.7% of farmers agreed that pollinator technology contributes to reducing environmental toxicity and residue, as reflected in a mean score of 4.22 (SD = 0.613). According to Isaacs (2021), integrated pest management (IPM) techniques which prioritize the preservation of pollinators like bees, can effectively control insect populations and increase agricultural yields while reducing the need for pesticides by up to 95%.

This suggests a strong recognition among farmers of the environmental benefits of the technology, particularly in reducing harmful residues that can result from traditional farming practices. The relatively low standard deviation indicates a consistent agreement across respondents, reinforcing the perception that pollinator technology aligns with sustainable farming practices. These findings highlight a complex interplay of perceived benefits and challenges associated with pollinator technology, emphasizing the need for a nuanced understanding of its overall impact on cocoa farming.

4.5 Factors influencing the adoption of pollinator technology

The model diagnostics demonstrates a strong goodness of fit for the logistic regression analysis on factors influencing pollinator technology adoption among cocoa farmers in the study area. The dependent variable's mean is 0.475, with a standard deviation of 0.500, indicating a balanced sample between adopters and non-adopters. The Pseudo R-squared value of 0.781 suggests a high explanatory power of the model, approximately 78.1% of the variance in pollinator technology adoption. The Chi-square statistic of 427.849 ($p < 0.001$) confirms the statistical significance of the model, validating the collective impact of the predictors on pollinator technology adoption.

Table 4.5: Factors influencing adoption of pollinator technology

Variable	Coefficient	Std. Error	z-value	p-value	Confidence interval		dy/dx
Age	-0.014	0.024	-0.60	0.549	-0.0619	0.0329	-0.0014
Household size	-0.090	0.140	-0.64	0.521	-0.3642	0.1846	-0.009
Education	0.305	0.492	0.62	0.535	-0.6593	1.2702	0.032***
Access to AEAs	2.620	0.912	2.87	0.004	0.8320	4.4080	0.354
Training	1.797	0.909	1.98	0.048	0.0161	3.5783	0.138**
Gender	0.110	0.768	0.14	0.886	-1.3955	1.6147	0.011
Labor use	0.358	0.929	0.39	0.700	-1.4623	2.1784	0.040
Land ownership	0.148	0.186	0.80	0.426	-0.2166	0.5134	0.015
Income	0.001	0.0002	6.17	0.000	0.0008	0.0015	0.000***
FBO membership	1.657	0.979	1.69	0.091	-0.2619	3.5768	0.010*
Access to credit	7.307	1.338	5.46	0.000	4.6851	9.9288	0.652***
Perception index	-0.137	0.897	-0.15	0.879	-1.8955	1.6215	-0.014
Constant	-8.519	3.845	-2.22	0.027	-16.0538	-0.9836	
Number of observations					396		
LR $\chi^2(12)$					427.87		
Prob > χ^2					0.0000		

Log likelihood	-60.0449
Pseudo R^2	0.7808

Source: Field survey, 2024

The findings showed in Table 4.5 reveals several significant factors influencing the adoption of cocoa pollinator technology among cocoa farmers in the Osino cocoa district.

The coefficient of 7.307 and marginal effect of 0.652 associated with access to credit has the largest marginal effect (0.652), indicating that it is the most influential factor among the variables analyzed suggesting that access to credit greatly increases the probability of the in adopting pollinator technology. This also shows that there is a significant relationship between financial resources and the likelihood of farmers adopting pollinator technology. Specifically, farmers who have access to credit facilities are substantially likely to implement this advanced farming practice. Access to credit provides the necessary financial resources to invest in new technologies and practices, which often require substantial upfront investments in equipment and training. Furthermore, the costs associated with pollinator technology adoption, including the purchase of tools and the hiring of labour, can be prohibitive without adequate funding (Potts et al. 2016). Access to credit also mitigates financial risk, allowing farmers to invest in risk-reducing technologies despite uncertainties related to weather and market fluctuations. By overcoming these financial barriers, credit facilitates the transition to more efficient farming methods and empowers farmers to make informed decisions about their operations. Thus, the significant positive effect of access to credit access pollinator technology adoption shows the important role of financial resources in promoting adoption of cocoa pollinator technology. This outcome aligns with findings of Girma (2022) who indicated that access to credit significantly enhances farmers' ability to invest in new agricultural technologies, overcoming financial barriers associated with substantial upfront costs for equipment and training. Also, the results are in consonance with the findings of Gelata and Han (2023) on their study on rural credit access and contract farming nexus in Ethiopia. They indicated that access to credit enables farmers to invest in risk-reducing technologies, thereby mitigating financial risks associated with uncertainties in weather and market fluctuations.

Both access to AEAs and training have been shown to have a positive influence on pollinator technology. The marginal effects on AEAs and training are 0.354 ($p = 0.004$) and 0.138 ($p = 0.048$) respectively. This indicates that AEAs and participation in training programmes significantly increases the probability of adopting pollinator technology. These findings highlight the pivotal role that extension services and training programmes play in promoting the uptake of innovative agricultural practices among cocoa farmers. AEAs serve as crucial intermediaries by providing farmers with relevant information, technical assistance, and practical guidance on integrating pollinator technology into their farming practices (Isaacs et al., 2017). Similarly, training programmes equip farmers with the necessary knowledge and skills to effectively implement and manage the technology, thereby enhancing their confidence and competence in its application (Raji et al., 2024). The positive impact of AEAs and training on adoption can be attributed to their ability to address information gaps, build capacity, and alleviate potential barriers that farmers may face in adopting new technologies (Hameed & Sawicka, 2023). By enhancing farmers' understanding and capabilities, AEAs and training contribute to fostering a supportive environment conducive to the successful adoption and integration of pollinator technology in cocoa farming (Asirifi et al., 2024).

The findings show that members of FBOs positively influence the adoption of pollinator technology, with a coefficient of 1.657 and a marginal effect associated with a 0.110 increase in the dependent variable. This implies that social networks within the farming communities plays essential role in creating an environment that supports the adoption of improved or new agricultural practices. Specifically, being part of an FBO can enhance farmers' access to peer support, which can be instrumental in alleviating uncertainties associated with implementing improved technologies. Such organizations often facilitate resource sharing among members, allowing farmers to collectively invest in expensive technologies or access training programmes that would be unaffordable individually (Akomaning et al., 2022; Paglietti & Sabrie, 2013). Additionally, FBOs create opportunities for collective learning, where farmers can exchange knowledge and experiences regarding pollinator technology adoption, thus building confidence in their ability to implement these practices effectively. The supportive social structure inherent in FBOs not only enhances individual farmers' capacity to adopt pollinator technology but also contributes to the overall resilience and sustainability of the farming community. The finding is also consistent with those of Onumah et al. (2014) who found that FBOs enhance farmers' access to peer support and resource sharing, enabling collective investment in technologies and training, thus reducing uncertainties in adopting innovative practices.

Results from the study again, showed that income is a positive factor influencing the adoption of pollinator technology, with a coefficient of 0.001, showing that higher income increases the probability of adopting pollinator technology among farmer. This finding indicates that farmers with high level of income are likely to adopt pollinator technology, as increased financial resources provide them with greater capacity to invest in innovative agricultural practices. Higher-income earning farmers are often better positioned to cover the various costs associated with pollinator technology adoption, including equipment purchases, supplementary labour, and access to training sessions or expert consultations that can enhance the effectiveness of the technology. Moreover, having a higher income may allow these farmers to experiment with pollinator technology without challenge of financial strain, as they have the resources to absorb any initial costs or risks that may accompany the integration of new technology into their existing farming practices. This financial flexibility enables high income earning farmers to adopt pollinator technology more readily and potentially realize productivity gains sooner, reinforcing their competitive advantage. This finding is consistent with the findings of Jaroenwanit et al., (2023) who indicated that higher income enables farmers to adopt smart farming technologies, mitigate financial risks and allowing experimentation with new practices without significant economic strain. The findings also corroborate with Li et al. (2023). They found that farmers with higher incomes are more readily to adopt technologies to mitigating financial risks and constraints, thus enhancing their credit behaviour and overall financial stability.

4.6 Impact of adoption of cocoa pollinator technology on productivity

The study's findings are strengthened by the results of the balancing and over-identification tests, which confirm the validity and reliability of the IPWRA employed to evaluate the impact of pollinator technology adoption on productivity and income. After applying the matching process, the standardized differences between the treated and control groups across key covariates such as age, education, experience, and household size were effectively minimized, all falling well below the conventional threshold of 0.1. This indicates a strong balance between the groups, ensuring that any differences in outcomes can be attributed to the adoption of pollinator technology rather than to other confounding factors. Additionally, the variance ratios, close to 1.0 in both the raw and weighted data, further demonstrate the success of the matching process in equalizing the groups. Moreover, the over-identification test results, with a Chi-square value of 6.9081 and a p-value of 0.7341 as presented in Appendix 2. This implies the covariates are well-balanced and that the instruments used in the analysis are valid. The high p-value indicates no evidence of model misspecification, thereby reinforcing the credibility of the study's estimates.

The plot presented in Figure 4.1, shows considerable overlap in the density of the propensity score for adopters and non-adopters of the pollinator technology. This is desirable because it implies that the treatment assigned is not completely determined by the covariate, and a fair comparison can be made.

Figure 4.1: Overlap plot

Source: Field survey, 2024

Impact on productivity

The findings revealed a significant impact of cocoa pollinator technology on cocoa productivity as presented in Table 4.6. Farmers who adopted pollinator technology experienced increase in yield, with an average enhancement of 406.82 kg/ha while non-adopters had average of 257.52

kg/ha. The results are statistically robust, as evidenced by a high z-value of 16.65 and a p-value of 0.000 for adopters and z-value of 26.62 and p-value of 0.000 for non-adopters. This indicates that the observed improvement is highly significant and not attributable to random variation. This shows that there can be significant gains in yields by utilizing production technologies such as the pollinator technology as found by Wongnaa et al. (2021).

The substantial difference in yields between adopters and non-adopters highlights a pronounced productivity gap. These findings underscore the effectiveness of cocoa pollinator technology in enhancing productivity (Abrol, 2015). The substantial yield advantage for adopters suggests that the technology plays a crucial role in improving cocoa production (Akintelu et al., 2019). This significant productivity boost not only benefits individual farmers but also has broader implications for the cocoa sector, potentially leading to increased overall production and economic gains.

Table 4.6: Impact of adoption of pollination technology on cocoa yield

Yield	Coefficient	std. err.	Z	P>z	[95% conf. interval]	
ATT						
(Adopters vs non-Adopters)	406.82	32.13	12.66	0.000***	343.85	469.79
POmean						
Non-Adopters	257.52	10.18	25.18	0.000***	237.48	277.56

Source: Field survey, 2024 Notes: *** *p<.01,* ** *p<.05,* * *p<.1*

The results in Table 4.7 revealed a significant impact of cocoa pollinator technology on cocoa income. Adopted of the pollinator technology had GHs 5,102.50 annual increase in income while non-adopters had GHs 3,240.64 average increase of income annually. Adams and Jumpah (2021) posited that adopters of agriculture technology are more likely to have increased income and hence can spend more money on food as compared to non-adopters. The substantial income advantage for adopters suggests that the technology plays a crucial role in improving cocoa productivity.

Table 4.7: Impact of adoption of pollination technology on cocoa income

Income	Coefficient	std. err.	Z	P>z	[95% conf. interval]	
ATT						
(Adopters vs. non-Adopters)	5102.50	398.32	12.81	0.000***	4321.80	5883.20
POmean						
Non-Adopters	3240.64	132.15	24.52	0.000***	2981.64	3499.64

Source: Field survey, 2024 Note: *** *p<.01,* ** *p<.05,* * *p<.1*

4.7 Constraints to pollinator technology adoption

The model diagnostics for analyzing the constraints faced by farmers in adopting pollinator technology in Table 4.8 provide valuable insights into the constraints encountered. The analysis reveals a substantial level of agreement by the respondents, with a Kendall's (W) value of 0.649. This coefficient indicates a high degree of consensus among the constraints. This suggests that the respondents uniformly perceive these barriers as impactful. The high Chi-Square value of 1807.4 indicates that the observed distribution of constraints is significantly different from what would be expected by chance, confirming that the constraints identified are meaningful and not random. The study identifies several key constraints impacting the adoption of pollinator technology. The most significant challenge is the inadequate information available on pollinator technology, which has the lowest mean score of 1.62. This lack of information severely impedes farmers' ability to effectively understand and utilize the technology.

Table 4.8: Constraints to pollinator technology adoption

Constraint	Mean	Rank

Inadequate information about Pollinator Technology	1.62	1st
Inadequate technical knowledge on pollinator technology	2.64	2nd
Lack of training on Pollinator Technology	2.87	3rd
Difficulty in managing Pollinator technology	4.42	4th
Pollinator Technology is labour intensive	5.11	5th
Pollinator Technology is costly to practice	5.70	6th
Seed quality is low on pollinator technology farm	6.74	7th
Low pods set on pollinator technology farms	6.91	8th

Statistics	
N	398
Kendall's W[a]	0.649
Chi-Square	1807.4
Df	7
Asymp. Sig.	0.000

Source: Field survey, 2024

According to Bello-Bravo and Lutomia (2023), agricultural information are hampered by low agent-to-farmer ratios and resource shortages, further limiting farmers' access to key innovations and best practices. Farmers have also expressed doubts about the effectiveness of community radio as a source of agricultural information, complicating their access to critical knowledge (Bello-Bravo & Lutomia, 2023). Closely related are issues of insufficient technical knowledge and lack of formal training, ranked second and third with mean scores of 2.64 and 2.87, respectively. These constraints highlight that farmer struggle not only with obtaining detailed information but also with accessing practical, hands-on training essential for successful implementation (Mishra et al., 2020). Ankuyi et al. (2023) argued that there is an urgent need for hands-on training in practical disciplines such as crop management and environmental adaptation, which is often inadequately addressed by existing educational frameworks. Further challenges include the complexities associated with managing the technology (mean = 4.42) and its labour-intensive nature (mean = 5.11). These factors require considerable effort and resources, adding to the difficulties faced by farmers. Additionally, the cost associated with pollinator technology, with a mean score of 5.70, presents a significant barrier, particularly for smallholder farmers with limited financial resources. For instance, Akinwale and Folarin (2018), stated that 80% of cocoa producers in Nigeria cite high pesticide costs as a barrier to adopting hybrid technology. Similarly, research in Ghana found that farmers faced problems such as high input costs and lack of access to funding, which hampers the implementation of recommended technologies (Mercy et al., 2015). Issues with seed quality (mean = 6.74) and low pod sets (mean = 6.91) on farms using the technology are also noteworthy. Farmers' capacity to adopt recommended agricultural innovations is hampered by a lack of availability of quality seeds and inefficiencies in the seed supply chain (Osei-Adu et al., 2016). They frequently rely on stored or low-quality seeds. These problems suggest that despite the adoption of the technology, other underlying factors may affect overall productivity.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents a summary of the study's findings, the conclusions drawn from the findings and the recommendations based on the conclusions.

5.2 Summary

Improving pollination in cocoa production is important to enhancing yields in Ghana. However, the decline of natural pollinators (midges) in cocoa has been identified by Ghana Cocoa Board as a major challenge to increasing cocoa production. This study was conducted to assess the impact of pollinator technology adoption on cocoa productivity in the Osino cocoa district in the Eastern region of Ghana. The multistage sampling was employed to select 400 cocoa farmers and a quasi-experimental research design. Adopters of the pollinator technology recorded a substantially higher mean yield (696.17 kg) than non-adopters (297.47 kg), with a mean difference of –398.70, significant at the 1% level ($p < 0.01$). Similarly, adopters earned significantly higher annual incomes (GH₵ 8,702.12) compared to non-adopters (GH₵ 3,718.39), reflecting a mean difference of GH₵ 4,983.72, also significant at the 1% level ($p < 0.01$). These results suggest that adoption of the pollination technology positively influenced productivity and farmers' income. Farming experience also differed significantly between the two groups, with adopters having slightly more experience (17.34 years) than non-adopters (16.08 years), and the difference was significant at the 5% level ($p = 0.0271$). This indicates that more experienced farmers were more inclined to adopt the technology. However, no significant differences were observed in age, household size, or total farm size, implying that these factors did not strongly influence adoption decisions.

The Chi-square analysis of socio-demographic characteristics further showed no statistically significant associations between adoption status and variables such as gender, education, marital status, religion, land ownership, membership in FBOs, and access to AEAs ($p > 0.05$ for all). Although most respondents were male (over 80% in both groups) and predominantly Christian, these factors did not significantly affect adoption. Similarly, while adopters tended to have slightly higher educational attainment and greater FBO participation, these differences were not statistically significant. The adoption of pollinator technology among respondents is relatively low, with 52.5% not adopting the technology and 47.5% having adopted the technology.

The farmers perceived that pollinator technology improve soil nutrient and yield and it is easy to practice. The study also perceived that pollinator technology does not increase the cost of agro-chemicals. The finding from the logistic regression analysis identified key factors influencing cocoa farmers' adoption of pollinator technology. Farmers' adoption of pollinator technology was significant with access to credit, being a member of a famer-based organization, availability of agricultural extension services, training and income. However, factors such as household size and age decreased the likelihood of adoption. The study showed that the use of pollinator technology positively affected cocoa productivity. Farmers who adopted the technology had an average yield increase, resulting in more income. The study highlighted constraints that farmers encounter when adopting pollinator technology. This includes limited access to information, a lack of technical expertise, absence of formal training, the complexity of managing the technology, its labour-intensive nature, high costs, poor seed quality, and low pod sets.

5.3 Conclusion

The study has shown that pollinator technology is influenced by social, economic and institutional factors. Being a member of a famer-based organization, training, access to credit facilities and, availability of agricultural extension services significantly influenced the adoption of pollinator technology positively. There farmers showed a positive perception about pollinator technology. The adoption of pollinator technology shows a substantial increase in cocoa productivity and income of the cocoa farmers. Despite the benefits of pollinator technology, constraints such as lack of information, technical knowledge gaps and labour-intensive nature of the technology limit its adoption among the cocoa farmers in the study area. This study illustrates that the adoption of improved agricultural technologies can lead to significant increases in productivity, often resulting in adopters achieving more than double the output of non-adopters. This study concludes that pollinator technology has a positive impact on cocoa productivity in the Osino cocoa district.

5.4 Recommendation

To enhance the adoption of pollinator technology and improve cocoa productivity in the Osino cocoa district in the Eastern region of Ghana, the following key recommendations are proposed. First, the Ghana Cocoa Board through the CRIG should intensify education and provide practical training on pollinator technology. Extension services should be expanded, with AEAs playing a crucial role in delivering these resources. This knowledge transfer from the AEAs can enhance confidence and encourage wider adoption of the technology.

To address economic barriers and support large households, financial institutions, including rural banks and microfinance institutions, should offer low-interest loans or grants specifically for agricultural technology adoption. NGOs working in the cocoa sector can collaborate with community leaders to create cooperative groups that pool resources and share labour, thus reducing the financial burden on individual farmers. Increasing awareness about pollinator technology is essential, and the government, through COCOBOD, should launch mass awareness campaigns. These efforts can be further supported by partnerships with other stakeholders in the cocoa value chain to ensure that accurate and comprehensive information reaches all cocoa farmers.

CRIG should also work on developing cost-effective and simplified versions of the technology to facilitate its broader adoption. Through these coordinated efforts, the challenges to adopting pollinator technology can be effectively addressed, leading to improved cocoa productivity in the region and Ghana at large.

REFERENCES

Abrol, D. P. (2015). Pollination and Fruit Productivity. In *Pollination Biology, Vol.1* (pp. 25–58). Springer International Publishing. https://doi.org/10.1007/978-3-319-21085-8_2

Acheampong, E. O., Sayer, J., Macgregor, C. J., & Sloan, S. (2021). Factors influencing the adoption of agricultural practices in Ghana's forest-fringe communities. *Land*, *10*(3), 266.

Adams, A., & Jumpah, E. T. (2021). Agricultural technologies adoption and smallholder farmers' welfare: Evidence from Northern Ghana. *Cogent Economics & Finance*, *9*(1), 2006905.

Addae, S., Acquah, S., & Essuman, S. N. (2024). Impact of Illegal Mining Activities on Cocoa Pollinator Abundance in Ghana. In *Shifting Frontiers of Theobroma Cacao-Opportunities and Challenges for Production*. IntechOpen.

Addai, K. N. (2015). Impact of Off- Farm Income on Hybrid Maize Adoption and Productivity of Maize Farmers across Various Agro Ecological Zones of Ghana. *Journal of economics and sustainable development, 6(3):41-48*.

Adebayo, S. T., Oyawole, F. P., Sanusi, R. A., & Afolami, C. A. (2022). Technology adoption among cocoa farmers in Nigeria: what drives farmers' decisions? *Forests, Trees and Livelihoods*, *31*(1), 1-12.

Adesida, I. E., Nkomoki, W., Bavorova, M., & Madaki, M. Y. (2021). Effects of agricultural programmes and land ownership on the adoption of sustainable agricultural practices in Nigeria. *Sustainability*, *13*(13), 7249.

Adjaloo, M. K., Owusu-Ansah, E., Oduro, W., & Fleischer, T. (2017). Preference of cocoa pollinators for different breeding substrates in a cocoa agroecosystem: a proxy approach. *Ghana Journal of Forestry*, *33*, 38-47.

Adjaloo, M., Banful, B. K. B., & Oduro, W. (2013). Evaluation of Breeding Substrates for Cocoa Pollinator, Forcipomyia spp. and Subsequent Implications for Yield in a Tropical Cocoa Production System. *American Journal of Plant Sciences*, *4*, 204-211.

Adjei-Nsiah, S., & Klerkx, L. (2016). Innovation platforms and institutional change: the case of small-scale palm oil processing in Ghana. *Cahiers Agricultures*.

Agbongiahuoyi, A. E., Taiwo, O., Solomon, F. B., & Oseni, J. O. (2014). Perception of cocoa farmers to voluntary standard certification: An implication on Cocoa Transformation in Nigeria. *IOSR Journal of Agriculture and Veterinary Science*, *7*(6), 17-20.

Ahmed, M. H. (2015). Adoption of multiple agricultural technologies in maize production of the Central Rift Valley of Ethiopia. *Studies in Agricultural Economics*, *117*(3), 162-168.

Aishi, I., Malik, R., Baba, S. H., Bhat, B. A., Tariq, S., Rather, T. A., & Islam, M. A. (2020). Socio-economic Correlates of Attitude of Youth of Fishing Communities towards Fishing Occupation in Kashmir Valley. *Int. J. Curr. Microbiol. App. Sci*, *9*(10), 172-178.

Aizen, M. A., Aguiar, S., Biesmeijer, J. C., Garibaldi, L. A., Inouye, D. W., Jung, C., ... & Seymour, C. L. (2019). Global agricultural productivity is threatened by increasing pollinator dependence without a parallel increase in crop diversification. *Global change biology*, *25*(10), 3516-3527.

Ajzen, I. (1991). The theory of planned behaviour. *Organizational behaviour and human decision processes*, *50*(2), 179-211.

Akber, N., Paltasingh, K. R., Mishra, A. K., & Goyari, P. (2024). Land Ownership Security, Farm Investment, and Investment Risk in Indian Agriculture: Evidence from Nationally Representative Survey. *Journal of Agricultural and Applied Economics*, *56*(2), 278-296.

Akintelu, S. O., Mele, L., Sobanke, V. O., & Adewunmi, M. (2019). Adoption of some cocoa production technologies by cocoa farmers in Kogi State, Nigeria. *International Journal of Agriculture Innovation, Technology and Globalisation*, *1*(1), 31-43.

Akinwale, J. A., & Folarin, O. E. (2018). Factors Influencing Farmers' Adoption of CRIN TC Cocoa Hybrid Technology in Oyo State, Nigeria. *Pelita Perkebunan (a Coffee and Cocoa Research Journal)*, *34*(3), 191-198.

Akomaning, E. O., Osei, C. K., Tetteh, R. O., Bakang, J. E. A., & Akomaning, J. E. (2022). Influence of FBO interaction with research and extension on the adoption of technologies by FBO members in the Central Region of Ghana. *African Journal of Agricultural Research*, *18*(8), 664-671.

Akudugu, M. A., Nkegbe, P. K., Wongnaa, C. A., & Millar, K. K. (2023). Technology adoption behaviours of farmers during crises: What are the key factors to consider?. *Journal of Agriculture and Food Research*, *14*, 100694.

Alao, J. S., & Shuaibu, R. B. (2013). Agroforestry practices and concepts in sustainable land use systems in Nigeria. *Journal of horticulture and forestry*, *5*(10), 156-159.

Ali, E. B., Awuni, J. A., & Danso-Abbeam, G. (2018). Determinants of fertilizer adoption among smallholder cocoa farmers in the Western Region of Ghana. *Cogent Food & Agriculture*, *4*(1), 1538589.

Amaza, P., Kwacha, A., & Kamara, A. (2007). Farmers' perceptions, profitability, and factors influencing the adoption of improved maize varieties in the Guinea Savannas of Nigeria. *IITA: Research to nourish Africa*.

Ameyaw, K. (2023). *Assessing Farmers' Knowledge and Socioeconomic Impacts of the Cocoa Hand Pollination Programme: The Case of the Atwima Nkwabiagya District, Ghana* (Doctoral dissertation, University of Cape Coast).

Amponsah-Doku, B., Daymond, A., Robinson, S., Atuah, L., & Sizmur, T. (2022). Improving soil health and closing the yield gap of cocoa production in Ghana–a review. *Scientific African*, *15*, e01075.

Anand, A., Singh, O., Agarwal, M., & Aggarwal, R. (2014, October). Modeling adoption process based on awareness and motivation of consumers. In *Proceedings of 3rd international conference on reliability, infocom technologies and optimization* (pp. 1-6). IEEE.

Aneani, F., & Ofori-Frimpong, K. (2013). An analysis of yield gap and some factors of cocoa (Theobroma cacao) yields in Ghana. *Sustainable Agriculture Research*, *2*(4).

Aneani, F., Anchirinah, V. M., Owusu-Ansah, F., & Asamoah, M. (2013). Adoption of some cocoa production technologies by cocoa farmers in Ghana. *Sustainable Agriculture Research*, *1*(1), 103-117.

Anil, K., Bhat, P. P., Prasad, R., Rajesh, C. M., Jadhav, A., Manohar, K. N., & Nandini, H. M. (2024). A Review on Impact of Modern Agricultural Extension Services on Smallholder Farm Productivity and Sustainability in India. *Journal of Experimental Agriculture International*, *46*(7), 1161-1172.

Anim-Kwapong, G. J., & Frimpong, E. B. (2005). Vulnerability of agriculture to climate change impact of climate change on cocoa production. *Accra, Ghana*.

Ankuyi, F., Tham-Agyekum, E. K., Bakang, J. E. A., Quayson, N., Okantah, D., Hope, T., ... & Wesley, R. R. (2023). Local voices for cocoa production: Experiences of Ghanaian cocoa farmers on community radio. *International Journal on Food, Agriculture and Natural Resources*, *4*(1), 34-43.

Ariyanto, A., Syaukat, Y., Hartoyo, S., & Sinaga, B. M. (2020). Technology adoption and technical efficiency of oil palm smallholder plantation in Riau and West Kalimantan. *Jurnal Manajemen & Agribisnis*, *17*(3), 239-239.

Arnold, S. E., Forbes, S. J., Hall, D. R., Farman, D. I., Bridgemohan, P., Spinelli, G. R., ... & Stevenson, P. C. (2019). Floral odors and the interaction between pollinating ceratopogonid midges and cacao. *Journal of Chemical Ecology*, *45*(10), 869-878.

Asamoah, M., Owusu-Ansah, F., Brannor, P. F., Ofori, S., & Darkwa, C. O. (2018). Farmers' knowledge and utilization of CRIG recommended technologies and perceptions of government policies to enhance cocoa productivity.

Asante, B. O., Etuah, S., Faizal, A., Mensah, A., Prah, S., Mensah, J. O., & Aidoo, R. (2023). Does adoption of cocoa hand pollination (CHP) improve welfare of farmers? Evidence from smallholder cocoa farmers in Ghana. *International Journal of Agricultural Sustainability*, *21*(1), 2253659.

Asante, P. A., Rahn, E., Zuidema, P. A., Rozendaal, D. M., van der Baan, M. E., Läderach, P., ... & Anten, N. P. (2022). The cocoa yield gap in Ghana: A quantification and an analysis of factors that could narrow the gap. *Agricultural Systems*, *201*, 103473.

Asare, R., Muilerman, S., & Anim-Kwapong, G. J. (2018). Good agronomic practices in cocoa cultivation: Rehabilitating cocoa farms. In *Achieving sustainable cultivation of cocoa* (pp. 197-224). Burleigh Dodds Science Publishing Limited.

Ashrit, R. R., & Thakur, M. K. (2021). Is awareness a defining factor in the adoption of sustainable agricultural practices? Evidence from small holder farmers in a southern state of India. *SN Social Sciences*, *1*, 1-20.

Asirifi, S., Amankwa, K., Ankuyi, F., & Tham-Agyekum, E. K. (2024). Implementation Evaluation of Cocoa Hand Pollination Programme in Ghana. *Pelita Perkebunan (a Coffee and Cocoa Research Journal)*, *40*(1), 76-90.

Aslan, S. A., Gundogdu, K. S., Yaslioglu, E. R. K. A. N., Kirmikil, M. Ü. G. E., & Arici, I. (2007). Personal, physical and socioeconomic factors affecting farmers' adoption of land consolidation. *Spanish Journal of Agricultural Research*, (2), 204-213.

Atsriku, G. E. (2020). The Adoption of Agriculture Technology in Small-Scale Farming in the Adumasa Community in Ghana. *Agricultural, Food and Environmental Studies. The Hague, The Netherlands*.

Avane, A., Amfo, B., Aidoo, R., & Mensah, J. O. (2022). Adoption of organic fertilizer for cocoa production in Ghana: perceptions and determinants. *African Journal of Science, Technology, Innovation and Development*, *14*(3), 718-729.

Ayaz, M., & Mughal, M. (2024). Farm Size and Productivity: The Role of Family Labour. *Economic Development and Cultural Change*, *72*(2), 959-995.

Ayenew, W., Lakew, T., & Kristos, E. H. (2020). Agricultural technology adoption and its impact on smallholder farmers welfare in Ethiopia. *African Journal of Agricultural Research*, *15*(3), 431-445.

Azumah, S. B., & Zakaria, A. (2019). Fertilizer subsidy and rice productivity in Ghana: A microeconomic study. *Journal of Agricultural Studies*, *7*(1), 82-102.

Baah, F. (2020). Ghana's Cocoa Sector: Productivity, Quality, and Sustainability Challenges. *Journal of Agricultural Economics and Development, 9(4), 72-83.*

Babbie, E. R. (2020). *The practice of social research*. Cengage Au.

Bagheri, A., Allahyari, M. S., & Ashouri, D. (2016). Interpretation on biological control adoption of the rice stem borer, Chilo suppressalis (Walker) in North Part of Iran: application for Technology Acceptance Model (TAM). *Egyptian Journal of Biological Pest Control*, *26*(1).

Baldock, K. C. (2020). Opportunities and threats for pollinator conservation in global towns and cities. *Current opinion in insect science*, *38*, 63-71.

Bastiaan, M. (1984). The sex life of flowers. *Facts on File Publishers, New York*, 110-111.

Belay, M., & Mengiste, M. (2023). The ex-post impact of agricultural technology adoption on poverty: Evidence from north Shewa zone of Amhara region, Ethiopia. *International Journal of Finance & Economics*, *28*(2), 1327-1337.

Bello-Bravo, J., & Lutomia, A. N. (2023). Using information technologies (ICTs) to improve Theobroma cocoa extension service: Lessons from the case of Ghanaian bean farmers. In *Shifting Frontiers of Theobroma Cacao-Opportunities and Challenges for Production*. IntechOpen.

Billes, D. J. (1941). Pollination of Theobroma cacao L. in Trinidad, BWI.

Boateng, K. O., Dankyi, E., Amponsah, I. K., Awudzi, G. K., Amponsah, E., & Darko, G. (2023). Knowledge, perception, and pesticide application practices among smallholder cocoa farmers in four Ghanaian cocoa-growing regions. *Toxicology Reports*, *10*, 46-55.

Bos, M. M., Sporn, S. G., & Gradstein, S. R. (2007). Is productivity of cacao impeded by epiphytes? An experimental approach. *Agriculture, ecosystems & environment*, *122*(4), 490-493.

Bosompem, M. (2019). Predictors of ex-ante adoption of precision agriculture technologies by cocoa farmers in Ghana. *Journal of sustainable development in Africa*, *21*(4).

Bosselmann, A. S., Boadi, S. A., Olwig, M. F., & Asare, R. (2023). Social challenges and opportunities in agroforestry: cocoa farmers' perspectives. *Agroforestry as Climate Change Adaptation: The Case of Cocoa Farming in Ghana*, 93-119.

Bridgemohan, P., Singh, K., Cazoe, E., Perry, G., Mohamed, A., & Bridgemohan, R. S. (2017). Cocoa floral phenology and pollin ation: Implications for productivity in Caribbean Islands. *Journal of Plant Breeding and Crop Science*, *9*(7), 106-117.

Brown, P., Daigneault, A., & Dawson, J. (2019). Age, values, farming objectives, past management decisions, and future intentions in New Zealand agriculture. *Journal of environmental management*, *231*, 110-120.

Bymolt, R., Laven, A., & Tyzler, M. (2018). Demystifying the cocoa sector in Ghana and Côte d'Ivoire. *The Royal Tropical Institute (KIT): Amsterdam, The Netherlands*, *110*, 111.

Castro Muñoz, CP, Panduro Tenazoa, NM, Velazco Castro, EV, & Iturraran Pinto, ES (2017). Evaluation of the reproductive phenology and production dynamics of cocoa (Theobroma cacao L.) clone CC- - 51. Big Bang Faustiniano , 6(1), 38-42.

Chaudhary, O. P., & Chand, R. (2017). Economic benefits of animal pollination to Indian agriculture. *Indian Journal of Agricultural Sciences*, *87*(9), 1117-1138.

Chauhan, D. S., Kamble, V. J., Padghan, P. V., Khandare, N. O., & Kamble, R. R. (2006). Dairy farming practices adopted in tribal area of Kinwat Tehsil (District-Nanded). *Indian Journal of Animal Research*, *40*(1), 64-66.

Christmann, S. (2019). Do we realize the full impact of pollinator loss on other ecosystem services and the challenges for any restoration in terrestrial areas? *Restoration Ecology*, *27*(4), 720 725.

Claus, G., Vanhove, W., Van Damme, P., & Smagghe, G. (2018). Challenges in cocoa pollination: The case of Côte d'Ivoire. *Pollination in plants*, *39*.

COCOBOD (2023). *Turnaround Strategy Paper*. Ghana Cocoa Board. Available at: https://www.mofep.gov.gh/sites/default/files/reports/economic/Cocobod-Turnaround-Strategy.pdf

Cragg, J. G. (1971). Some statistical models for limited dependent variables with application to the demand for durable goods. *Econometrica: journal of the Econometric Society*, 829 844.

Dani, D., & Rokhmah, D. N. (2022). A review of the role of pollination on the yield of cocoa plant. *Kultivasi*, *21*(3).

Das, B., & Das, A. (2017). Technology adoption in Indian agriculture and its determinants: An inter-state analysis. In *Indian Agriculture after the Green Revolution* (pp. 112-129). Routledge.

Davis, F. D. (1989). Technology acceptance model: TAM. *Al-Suqri, MN, Al-Aufi, AS: Information Seeking Behaviour and Technology Adoption*, *205*, 219.

Debeuckelaere, K., Janssens, D., Serral Asensio, E., Wenseleers, T., Jacquemyn, H., & Pozo, M. I. (2024). A wireless, remotely operable and easily customizable robotic flower system. *Methods in Ecology and Evolution*.

Degaga, J., Alemu, G., & Angasu, B. (2020). Factors affecting adoption of improved haricot bean (Phaseolus Vulagris L) technology in West Hararghe zone of Oromia region, Ethiopia: A Heckman two-step approach. *Trop. Agric*, *41*(3216), 040253-267.

Dillman, D. A., Smyth, J. D., & Christian, L. M. (2014). *Internet, phone, mail, and mixed-mode surveys: The tailored design method*. John Wiley & Sons.

Dixit, P., Gupta, A., Dwivedi, L. K., & Coomar, D. (2018). Impact evaluation of integrated child development services in rural India: Propensity score matching analysis. *Sage Open*, *8*(2), 2158244018785713.

Djokoto, J. G., Owusu, V., & Awunyo-Vitor, D. (2016). Adoption of organic agriculture: Evidence from cocoa farming in Ghana. *Cogent Food & Agriculture*, *2*(1), 1242181.

Donovan, J., Stoian, D., Foundjem, D., & Degrande, A. (2016). Fairtrade cocoa in Ghana: taking stock and looking ahead. *Sweet Vision*, *61*(3).

Dormon, E. V., Van Huis, A., Leeuwis, C., Obeng-Ofori, D., & Sakyi-Dawson, O. (2004). Causes of low productivity of cocoa in Ghana: farmers' perspectives and insights from research and the socio-political establishment. *NJAS: Wageningen Journal of Life Sciences*, *52*(3 4), 237-259.

Eardley, C. D., Gikungu, M., & Schwarz, M. P. (2009). Bee conservation in Sub-Saharan Africa and Madagascar: diversity, status and threats. *Apidologie*, *40*(3), 355-366.

Elisante, F., Ndakidemi, P. A., Arnold, S. E., Belmain, S. R., Gurr, G. M., Darbyshire, I., ... & Stevenson, P. C. (2019). Enhancing knowledge among smallholders on pollinators and supporting field margins for sustainable food security. *Journal of Rural Studies*, *70*, 75 86.

FAOSTAT. (2018). Retrieved from: http://www.fao.org/faostat/en/#data/QC on June 14, 2024

FAOSTAT. (2020). Food and Agriculture Organization of the United Nations (FAO). FAOSTAT Database. https://www.fao.org/faostat/en/#data/QC L. Accessed 02/07/2024

Far, S. T., & Rezaei-Moghaddam, K. (2017). Determinants of Iranian agricultural consultants' intentions toward precision agriculture: Integrating innovativeness to the technology acceptance model. *Journal of the Saudi Society of Agricultural Sciences*, *16*(3), 280-286

Fijen, T. P., Scheper, J. A., Vogel, C., van Ruijven, J., & Kleijn, D. (2020). Insect pollination is the weakest link in the production of a hybrid seed crop. *Agriculture, Ecosystems & Environment*, *290*, 106743.

Food and Agriculture Organization of the United Nations (FAO). (2023). *FAOSTAT: Crops and livestock products – Cocoa beans, Ghana.* Retrieved from https://www.fao.org/faostat

Forbes, S. J., & Northfield, T. D. (2017). Increased pollinator habitat enhances cacao fruit set and predator conservation. *Ecological applications*, *27*(3), 887-899.

Fountain, A., & Hütz-Adams, F. (2018). Cocoa barometer (No. BOOK_B). *Public Eye*.

Fredriksson, A., & Oliveira, G. M. D. (2019). Impact evaluation using Difference-in-Differences. *RAUSP Management Journal*, *54*, 519-532.

Frimpong, E. A., Gemmill-Herren, B., Gordon, I., & Kwapong, P. K. (2011). Dynamics of insect pollinators as influenced by cocoa production systems in Ghana. *Journal of Pollination Ecology*, 74-80.

Frimpong, E. A., Gordon, I., Kwapong, P. K., & Gemmill-Herren, B. (2009). Dynamics of cocoa pollination: tools and applications for surveying and monitoring cocoa pollinators. *International Journal of Tropical Insect Science*, *29*(2), 62-69.

Frimpong-Anin, K., & Kwapong, P. (2020). Substrate management for cocoa pollinating midges. *Towards sustainable crop pollination services*, 45.

Frimpong-Anin, K., Adjaloo, M. K., Kwapong, P. K., & Oduro, W. (2014). Structure and stability of cocoa flowers and their response to pollination. *Journal of Botany*, *2014*(1), 513623.

Frimpong-Anin, K., Kwapong, P. K., & Gordon, I. (2013). Cocoa farmers' awareness of pollination and its implication for pollinator-friendly practices. *Research and Reviews in Biosciences*, *7*(12), 504-512.

Fröhlich, M., Frölich, M., & Sperlich, S. (2019). *Impact evaluation*. Cambridge University Press.

Ganeshkumar, C., Singh, N. K., Mor, R. S., & Panghal, A. (2023). Investigating the Adoption Barriers to Industry 4.0 Technologies in Farmer Producer Organisations. *International Journal of Global Business and Competitiveness*, *18*(2), 162-174.

Gassner, A., Harris, D., Mausch, K., Terheggen, A., Lopes, C., Finlayson, R. F., & Dobie, P. (2019). Poverty eradication and food security through agriculture in Africa: Rethinking objectives and entry points. *Outlook on agriculture*, *48*(4), 309-315.

Gebeyehu, M. G. (2016). The impact of technology adoption on agricultural productivity and production risk in Ethiopia: Evidence from rural Amhara household survey. *Open Access Library Journal*, *3*(2), 1-14.

Gedikoglu, H., & Parcell, J. L. (2013). Impact of Earned and Unearned Off-Farm Income on Adoption of New Technologies. doi: 10.22004/AG.ECON.149702

Gelata, F. T., & Han, J. (2023). Rural credit access and contract farming nexus in Ethiopia: A meta-analysis. Heliyon, doi: 10.1016/j.heliyon.2023.e23154

Ghana Statistical Service (2014). '2010 Population and Housing Census: District Analytical Report'. Ghana Statistical Service, October 2014. Retrieved from; http://www.statsghana.gov.gh. on January, 2025

Girma, Y. (2022). Credit access and agricultural technology adoption nexus in Ethiopia: A systematic review and meta-analysis. *Journal of Agriculture and Food Research*, *10*, 100362.

Glendinning, D. R. (1972). Natural pollination of cocoa. *The New Phytologist*, *71*(4), 719-729.

Groeneveld, J. H., Tscharntke, T., Moser, G., & Clough, Y. (2010). Experimental evidence for stronger cacao yield limitation by pollination than by plant resources. *Perspectives in Plant Ecology, Evolution and Systematics*, *12*(3), 183-191.

Hameed, T. S., & Sawicka, B. (2017). The importance of opinion leaders in agricultural extension. *World Scientific News*, *76*, 31-37.

Hameed, T. S., & Sawicka, B. (2023). Role of Agricultural Extension in Adoption of Sustainable Agriculture Practices. *Anbar Journal of Agricultural Sciences*, *21*(1).

Harikrishna, Y., Hansdah, P., & Sharma, N. (2022). Farmer's producer organisation (FPO) collective steps towards lucrative agriculture. *Asian Journal of Agricultural Extension, Economics & Sociology*, 60-65.

Herrera Arango, M., Restrepo Campuzano, L., Orozco Mendoza, G. L., Hincapie Llanos, G. A., & Zartha Sossa, J. W. (2023). Drivers to Adopt Activities Framed within Sustainable Agriculture. *Ciencia y Tecnología Agropecuaria*, *24*(3).

Hevia, V., García-Llorente, M., Martínez-Sastre, R., Palomo, S., García, D., Miñarro, M., ... & Gonzalez, J. A. (2021). Do farmers care about pollinators? A cross-site comparison of farmers' perceptions, knowledge, and management practices for pollinator-dependent crops. *International Journal of Agricultural Sustainability*, *19*(1), 1-15.

Hill, R., Nates-Parra, G., Quezada-Euán, J. J. G., Buchori, D., LeBuhn, G., Maués, M. M., ... & Roué, M. (2019). Biocultural approaches to pollinator conservation. *Nature Sustainability*, *2*(3), 214-222.

Holland, J. N., & DeAngelis, D. L. (2002). Ecological and evolutionary conditions for fruit abortion to regulate pollinating seed-eaters and increase plant reproduction. *Theoretical Population Biology*, *61*(3), 251-263.

Hossan, D., Dato'Mansor, Z., & Jaharuddin, N. S. (2023). Research population and sampling in quantitative study. *International Journal of Business and Technopreneurship (IJBT)*, *13*(3), 209-222.

Huang, E., & Zhu, Y. (2024). Off-farm work, adoption of resource-conservation technology, and farm performance: evidence from banana farmers in China. *Applied Economics*, 1-15.

Ilesanmi, J. O., & Afolabi, J. A. (2020). Determinants of adoption of improved Cocoa technologies in Ekiti state, Nigeria. *International Journal of Agricultural Economics*, *5*(2), 36.

International Cocoa Organization (ICCO). (2022, 2023, 2024). *Quarterly bulletin of cocoa statistics*. International Cocoa Organization. Retrieved from Statistics - International Cocoa Organization

Isaacs, R. (2021). Integrated pest management can still deliver on its promise, with help from the bees. *Proceedings of the National Academy of Sciences*, *118*(48), e2118532118.

Isaacs, R., Williams, N., Ellis, J., Pitts-Singer, T. L., Bommarco, R., & Vaughan, M. (2017). Integrated crop pollination: combining strategies to ensure stable and sustainable yields of pollination-dependent crops. *Basic and Applied Ecology*, *22*, 44-60.

Jaramillo, M. A., Reyes-Palencia, J., & Jiménez, P. (2024). Floral biology and flower visitors of cocoa (Theobroma cacao L.) in the upper Magdalena Valley, Colombia. *Flora*, *313*, 152480.

Jaroenwanit, P., Phuensane, P., Sekhari, A., & Gay, C. (2023). Risk management in the adoption of smart farming technologies by rural farmers. *Uncertain Supply Chain Management*, *11*(2), 533-546.

Jebuni-Dotsey, S., Senadza, B., & Akpalu, W. (2023). Valuing Pollination as an Ecosystem Services: The Case of Hand Pollination for Cocoa Production in Ghana. *Journal of Agricultural Science*, *15*(8).

Jha, S., Kaechele, H., & Sieber, S. (2021). Factors influencing the adoption of agroforestry by smallholder farmer households in Tanzania: Case studies from Morogoro and Dodoma. *Land use policy*, *103*, 105308.

Kalogiannidis, S., & Syndoukas, D. (2024). The impact of agricultural extension services on farm output: A worldwide viewpoint. *Research on World Agricultural Economy*, *5*(1), 96-114.

Kane, L. T., Fang, T., Galetta, M. S., Goyal, D. K., Nicholson, K. J., Kepler, C. K., ... & Schroeder, G. D. (2020). Propensity score matching: a statistical method. *Clinical spine surgery*, *33*(3), 120-122.

Karbo, R. T. V., Frewer, L. J., Areal, F., Jones, G., & Nurudeen, S. (2024). A systematic review of the efficacy of theories used to understand farmers' technology adoption behaviour in lower-to-middle-income countries. *Development Studies Research*, *11*(1), 2294696.

Kaufmann, T. (1975). Studies on the ecology and biology of a cocoa pollinator. *Forcipomyia squamipennis I and. M. (Diptera, Ceratopogonidae)*, in Ghana. *Bulleting of Entomological Research. 1975;65:263-268*

Kehinde, A. D., Akinola, A., & Ogundeji, A. A. (2022). Agricultural Organizations and Adoption of Soil Conservation Practices Among Smallholder Farmers In Oyo State, Nigeria. *Tropical and Subtropical Agroecosystems*, *25*(3).

Kernecker, M., Knierim, A., Wurbs, A., Kraus, T., & Borges, F. (2020). Experience versus expectation: Farmers' perceptions of smart farming technologies for cropping systems across Europe. *Precision Agriculture*, *21*, 34-50.

Kleijn, D., Winfree, R., Bartomeus, I., Carvalheiro, L. G., Henry, M., Isaacs, R., ... & Potts, S. G. (2015). Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. *Nature communications*, *6*(1), 7414.

Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the royal society B: biological sciences*, *274*(1608), 303-313.

Knapp, J. L., Bartlett, L. J., & Osborne, J. L. (2017). Re-evaluating strategies for pollinator-dependent crops: How useful is parthenocarpy?. *Journal of Applied Ecology*, *54*(4), 1171-1179.

Kotrlik, J. W. K. J. W., & Higgins, C. C. H. C. C. (2001). Organizational research: Determining appropriate sample size in survey research appropriate sample size in survey research. *Information technology, learning, and performance journal*, *19*(1), 43.

Kovács-Hostyánszki, A., Espíndola, A., Vanbergen, A. J., Settele, J., Kremen, C., & Dicks, L. V. (2017). Ecological intensification to mitigate impacts of conventional intensive land use on pollinators and pollination. *Ecology letters*, *20*(5), 673-689.

Kremen, C., & M'Gonigle, L. K. (2015). Small-scale restoration in intensive agricultural landscapes supports more specialized and less mobile pollinator species. *Journal of applied Ecology*, *52*(3), 602-610.

Kumar, S., Singh, D. R., Singh, A., Singh, N. P., & Jha, G. K. (2020). Does adoption of soil and water conservation practice enhance productivity and reduce risk exposure? Empirical evidence from semi-arid tropics (SAT), India. *Sustainability*, *12*(17), 6965.

Kwadzo, G. T., Kuwornu, J. K., & Amadu, I. S. (2013). Food crop farmers' willingness to participate in market-based crop insurance scheme: Evidence from Ghana. *Research in Applied Economics*, *5*(1), 1.

Kyei, L., Foli, G., & Ankoh, J. (2011). Analysis of factors affecting the technical efficiency of cocoa farmers in the Offinso district-Ashanti region, Ghana. *American journal of social and management sciences*, *2*(2), 208-216.

La Barbera, F., & Ajzen, I. (2021). Moderating role of perceived behavioural control in the theory of planned behaviour: A preregistered study. *Journal of Theoretical Social Psychology*, *5*(1), 35-45.

Lambert, A. (2014). The fairness gap: Farmer incomes and root cause solutions to ending child labour in the cocoa industry. International Labour Rights Forum.

Lander, T. A., Atta-Boateng, A., Toledo-Hernández, M., Wood, A., Malhi, Y., Solé, M., ... & Wanger, T. C. (2025). Global chocolate supply is limited by low pollination and high temperatures. *Communications Earth & Environment*, *6*(1), 97.

Läpple, D., & Kelley, H. (2013). Understanding the uptake of organic farming: Accounting for heterogeneities among Irish farmers. *Ecological Economics*, *88*, 11-19.

Leeuwis, C., & Aarts, N. (2020). Rethinking adoption and diffusion as a collective social process: towards an interactional perspective. In *The innovation revolution in agriculture: A roadmap to value creation* (pp. 95-116). Cham: Springer International Publishing.

Li, F., Zang, D., Chandio, A. A., Yang, D., & Jiang, Y. (2023). Farmers' adoption of digital technology and agricultural entrepreneurial willingness: Evidence from China. *Technology in Society*, *73*, 102253.

Lippert, C., Feuerbacher, A., & Narjes, M. (2021). Revisiting the economic valuation of agricultural losses due to large-scale changes in pollinator populations. *Ecological Economics*, *180*, 106860.

Loki, O. (2022). Farmers' perceptions towards privatisation of extension services in eastern cape and kwazulu-natal provinces of South Africa. *Journal of International Agricultural and Extension Education*, *29*(4), 27-53.

Lopez, M. E., Ramirez, O. A., Dubon, A., Ribeiro, T. H. C., Diaz, F. J., & Chalfun-Junior, A. (2021). Sexual compatibility in cacao clones drives arrangements in the field leading to high yield. *Scientia Horticulturae*, *287*, 110276.Dormon et al. (2004

Lu, J., Li, M., & Hou, C. (2022). A weighted average distributed estimator for high dimensional parameter. *arXiv preprint arXiv:2206.02204*.

Maguire-Rajpaul, V. A., Khatun, K., & Hirons, M. A. (2020). Agricultural information's impact on the adaptive capacity of Ghana's smallholder cocoa farmers. *Frontiers in Sustainable Food Systems*, *4*, 28.

Mahmud, K. T., Haque, A. M., Wahid, I. S., Parvez, A., & Kabir, F. (2022). Impact of microcredit on the household income and expenditure of the fish farmers: Bangladesh perspective. *Aquaculture Economics & Management*, *26*(1), 118-130.

Marangunić, N., & Granić, A. (2015). Technology acceptance model: a literature review from 1986 to 2013. *Universal access in the information society*, *14*, 81-95.

Marenya, P. P., & Usman, M. A. (2021). Community-embedded experiential learning and adoption of conservation farming practices in Eastern and SouthernAfrica. *Environmental Development*, *40*, 100672.

Marques, A. P., Santo, A. D. S. D. E., Berssaneti, A. A., Matsutani, L. A., & Yuan, S. L. K. (2017).Prevalence of fibromyalgia: literature review update. Revista brasileira de reumatologia, 57(4), 356-363.

Matous, P., & Bodin, Ö. (2024). Hub-and-spoke social networks among Indonesian cocoa farmers homogenise farming practices. *People and Nature*, *6*(2), 598-609.

Mawar, P. C., & Adiati, L. (2024). Analysis Of Behavioural Determinants Preventing Food Waste in Consumers Based on the Theory Of Planned Behaviour (TPB) Mediated By Behaviour Intention. *International Journal of Engineering Business and Social Science*, 2(04), 1176 1185.

Mbam, B. N., & Nwibo, S. U. (2013). Entrepreneurship development as a strategy for poverty alleviation among farming households in Igbo-Eze North Local Government Area of Enugu State, Nigeria. *Greener Journal of Agricultural Sciences*, *3*(10), 736-742.

McDonald, J. H. (2009). *Handbook of biological statistics* (Vol. 2, pp. 6-59). Baltimore, MD: sparky house publishing.

Megdelawit, T., & Sisay D. (2023). Adoption of Coffee Technologies: A Multivariate Probit Model. *International Journal of Theoretical and Applied Mathematics 10(1)*

Meijer, S. S., Catacutan, D., Ajayi, O. C., Sileshi, G. W., & Nieuwenhuis, M. (2015). The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. *International journal of agricultural sustainability*, *13*(1), 40-54.

Mekonnen, T. (2017). Productivity and household welfare impact of technology adoption: Micro-level evidence from rural Ethiopia. *UNU-MERIT working paper series*, *7*.

Mercy, A., Aneani, F., Ofori, S., & Branor, P. F. (2015). Analysis of farmers adoption behaviour of CRIG recommended technologies as a package: The case of some self-help cocoa farmer associations in the Eastern Region of Ghana. *Agricultural Sciences*, *6*(6), 601 608.

Mgendi, G., Mao, S., & Qiao, F. (2022). Does agricultural training and demonstration matter in technology adoption? The empirical evidence from small rice farmers in Tanzania. *Technology in Society*, *70*, 102024.

Miñarro, M., & Twizell, K. W. (2015). Pollination services provided by wild insects to kiwifruit (Actinidia deliciosa). *Apidologie*, *46*, 276-285.

Misganaw, M., Mengesha, G., & Awas, T. (2017). Perception of farmers on importance of insect pollinators in Gozamin district of Amhara region, Ethiopia. *Biodiversity International Journal*, *1*(5), 54-60.

Mishra, A., Yadav, O. P., Yadav, V., & Pratap, S. (2020). Constraints faced by farmers and suggestions for effective utilization of ICT services in agriculture in central UP. *The Pharma Innovation Journal*, *9*(2), 121-124.

Mottaleb, K. A. (2018). Perception and adoption of a new agricultural technology: Evidence from a developing country. *Technology in society*, *55*, 126-135.

Munćan, P., & Božić, D. (2017). Farm size as a factor of employment and income of members of family farms. *Економика пољопривреде*, *64*(4), 1483-1498.

Munyao, C. M., Muisu, F., Mbego, J., Mburu, F., & Sirmah, P. (2013). Influence of Land Size on Adoption of Jatropha Curcas in Yatta District, Kenya. Journal of Natural Sciences Research, 3(4):42-50.

Mwangi, M., & Kariuki, S. (2015). Factors determining adoption of new agricultural technology by smallholder farmers in developing countries. *Journal of Economics and sustainable development*, *6*(5).

Nabhani, I., Daryanto, A., & Rifin, A. (2016). Mobile broadband for the farmers: a case study of technology adoption by cocoa farmers in Southern East Java, Indonesia. *AGRIS on-line Papers in Economics and Informatics*, *8*(2), 111-120.

Nagar, A., Nauriyal, D. K., & Singh, S. (2024). Factors Influencing Adoption of Technical Advice from Agricultural Extension Services: Evidence from a Field Survey in Western Uttar Pradesh, India. *The Indian Economic Journal*, 00194662241254502.

Ndah, H. T., Schuler, J., Uthes, S., Zander, P., Traore, K., Gama, M. S., ... & Corbeels, M. (2014). Adoption potential of conservation agriculture practices in sub-Saharan Africa: results from five case studies. *Environmental management*, *53*, 620-635.

Ndombi, C. L. (2015). *Influence of training programme on transfer level of agricultural best practices by farmers: the case of Gandini irrigation project, Kilifi county, Kenya* (Doctoral dissertation, University of Nairobi).

Nnahiwe, P., Hejkrlík, J., & Bavorová, M. (2023). Adopting modern agricultural technologies and impact on economic performance: evidence from cashew farmers in Kenya. *International Food and Agribusiness Management Review*, *26*(4), 615-639.

Nyirahabimana, H., Turinawe, A., Lederer, J., Karungi, J., & Herrnegger, M. (2021). What influences farmer's adoption lag for soil and water conservation practices? Evidence from Sio-Malaba Malakisi River Basin of Kenya and Uganda borders. *Agronomy*, *11*(10), 1985.

O'Sullivan, R., Fischer, J. E., Antwi, Y. A., & Freudenberger, M. (2021). Rooted in the ground: Reforming Ghana's forest laws to incentivize cocoa based agroforestry. *USAID* Retrieved https://www.land-links.org/wp-content/uploads/2021/03/ILRG-Ghana-Tree Tenure-Paper final. pdf. Accessed on June 23, 2024

Okali, C. (2013). *Cocoa & Kinship In Guana*. Routledge.

Onumah, J. A., Williams, P. A., Quaye, W., Akuffobea, M., & Onumah, E. E. (2014). Smallholder cocoa farmers' access to on/off-farm support services and its contribution to output in the eastern region of Ghana. *Asian Journal of Agriculture and Rural Development*, *4*(10), 484 495.

Osei-Adu, J., Bonsu, O., Ekyem, S. O., Afari-Sefa, V., & Osei, M. K. (2016). Structure of Cocoa Based Vegetable Seed System for Selected Locale in Ghana. *Sustainable Agriculture Research*, *5*(4).

Paglietti, L., & Sabrie, R. (2013). Review of smallholder linkages for inclusive agribusiness development. FAO Investment Centre. *Best practices in investment design (FAO) eng*, (7).

Perera, C. H., Nayak, R., & Nguyen, L. V. T. (2022). Quantitative Data Presentation and Analysis: Descriptive Analysis. In *Social Media Marketing and Customer-Based Brand Equity for Higher Educational Institutions: Case of Vietnam and Sri Lanka* (pp.169 186). Singapore: Springer Nature Singapore.

Phillips, F. Y., & Phillips, F. Y. (2001). Influence of Government Policy on Technology Acquisition and Utilization. *Market-Oriented Technology Management: Innovating for Profit in Entrepreneurial Times*, 193-223.

Popovic, M., Zugna, D., Tilling, K., & Richiardi, L. (2024). Regression discontinuity design for the study of health effects of exposures acting early in life. *Frontiers in Public Health*, *12*, 1377456.

Posnette, A. F. (1947). Virus diseases of cacao in West Africa: I. Cacao Viruses 1A, 1B, 1C and 1D. *Annals of Applied Biology*, *34*(3), 388-402.

Potts, S. G., Imperatriz-Fonseca, V., Ngo, H. T., Aizen, M. A., Biesmeijer, J. C., Breeze, T. D., ... & Vanbergen, A. J. (2016). Safeguarding pollinators and their values to human well-being. *Nature*, *540*(7632), 220-229.

Pretty, J., & Bharucha, Z. P. (2014). Sustainable intensification in agricultural systems. *Annals of botany*, *114*(8), 1571-1596.

Purwanto, S., & Rini, H. P. (2022). Analysis of Green Self Identity and Environment Concern on Adopt Electric Vehicle Intention with Perception of EV and Subjective Norm as Mediation Variables. *International Journal of Social Service and Research*, *2*(10),964 976.

Puspita, A. T. (2023). Attitude, Subjective Norm, and Perceived Behavioural Control on Halal Food Purchasing Behaviour: A Case in Indonesia. *Applied Marketing and Sustainability*, *1*(1).

Puth, M. T., Neuhäuser, M., & Ruxton, G. D. (2015). Effective use of Spearman's and Kendall's correlation coefficients for association between two measured traits. *Animal Behaviour*, *102*, 77-84.

Raji, E., Ijomah, T. I., & Eyieyien, O. G. (2024). Improving agricultural practices and productivity through extension services and innovative training programmes. *International Journal of Applied Research in Social Sciences*, *6*(7), 1297-1309.

Ramos‐Jiliberto, R., Moisset de Espanés, P., & Vázquez, D. P. (2020). Pollinator declines and the stability of plant–pollinator networks. *Ecosphere*, *11*(4), e03069.

Rawluk, A., & Saunders, M. E. (2019). Facing the gap: Exploring research on local knowledge of insect-provided services in agroecosystems. *International Journal of Agricultural Sustainability*, *17*(1), 108-117.

Raya, A. B., Kriska, M., Fatonah, S., Andiani, R., Seleky, R. N., Witjaksono, R., & Harsoyo, H. (2024). The Popularity of Extension Workers in the Exchange of Information on Yard Utilization. *Komunikator*, *16*(1), 104-117.

Regassa, M. D., Degnet, M. B., & Melesse, M. B. (2023). Access to credit and heterogeneous effects on agricultural technology adoption: Evidence from large rural surveys in Ethiopia. *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie*, *71*(2), 231-253.

Remiro‐Azócar, A. (2022). Purely prognostic variables may modify marginal treatment effects for non-collapsible effect measures. *arXiv preprint arXiv:2210.01757*.

Rhodes, C. J. (2018). Pollinator decline–an ecological calamity in the making? *Science progress*, *101*(2), 121-160.

Riyadh, Z. A., Rahman, M. A., Saha, S. R., Ahamed, T., & Current, D. (2021). Adaptation of agroforestry as a climate smart agriculture technology in Bangladesh. *International Journal of Agricultural Research, Innovation and Technology (IJARIT)*, *11*(1), 49-59.

Rogers, E. M. (1995). Diffusion of Innovations: modifications of a model for telecommunications. *Die diffusion von innovationen in der telekommunikation*, 25-38.

Rogers, E. M., Singhal, A., & Quinlan, M. M. (2014). Diffusion of innovations. In *An integrated approach to communication theory and research* (pp. 432-448). Routledge.

Rogers, E.M. (2003). *Diffusion of innovations* (5th ed.). New York: Free Press.

Roth, M., Antwi, Y., & O'Sullivan, R. (2017). Land and natural resource governance and tenure for enabling sustainable cocoa cultivation in Ghana. *Washington, DC: USAID Tenure and Global Climate Change Programme.*

Sadat, A., Ghosh, S. K., & Chakraborty, K. (2017). Impact of training on knowledge and adoption of jute technology in Uttar Dinajpur district of West Bengal, India. *Indian Research Journal of Extension Education*, *17*(2), 73-77.

Saha, L., & Bauddh, K. (2020). Sustainable agricultural approaches for enhanced crop productivity, better soil health, and improved ecosystem services. *Ecological and Practical Applications for Sustainable Agriculture*, 1-23.

Sajeev, M. V., Saroj, P. L., & Lakshmisha, R. (2014). Technology impacts on area, production and productivity of cashew in Dakshina Kannada district, Karnataka. *Journal of Plantation Crops*, *42*(1), 62-69.

Samanta, D. (2023). Estimating impact of technological adoption in farming in Bihar: a propensity score matching approach. *International Journal of Social Economics*, *50*(7), 1007-1016.

Sant'Anna, P. H., & Xu, Q. (2023). Difference-in-differences with compositional changes. *arXiv preprint arXiv:2304.13925*.

Saripah, B. (2013). Population enhancement of cocoa pollinator, Forcipomyia spp. In *Proceedings of Malaysian International Cocoa Conference (MICC 2013)* (pp. 144 150).

Saripah, B., & Alias, A. (2018). The use of transferable breeding container for population enrichment of pollinator, Forcipomyia spp. in the cocoa ecosystem. *Journal of Advanced Agricultural Technologies Vol*, *5*(3).

Sawe, T., Nielsen, A., Totland, O., Macrice, S., & Eldegard, K. (2020). Inadequate pollination services limit watermelon yields in northern Tanzania. *Basic and Applied Ecology*, *44*, 35-45.

Schepers, J., & Wetzels, M. (2007). A meta-analysis of the technology acceptance model: Investigating subjective norm and moderation effects. *Information & management*, *44*(1), 90-103.

Schneider, M., Winchester, C., Goldman, E., & Shao, Y. (2023). Mapping cocoa and assessing deforestation risk for the cocoa sector in Côte d'Ivoire and Ghana. *Technical Note. Washington, DC: World Resources Institute. https://www. wri. org/re search/mapping cocoa-assessing-deforestation-risk-cocoa-cote-divoire-ghana*.

Schroth, G., Läderach, P., Martinez-Valle, A. I., Bunn, C., & Jassogne, L. (2016). Vulnerability to climate change of cocoa in West Africa: Patterns, opportunities and limits to adaptation. *Science of the Total Environment*, *556*, 231-241.

Schulte, I., Landholm, D. M., Bakhtary, H., Cabezas, S. C., Siantidis, S., Manirajah, S. M., & Streck, C. (2020). Supporting smallholder farmers for a sustainable cocoa sector: Exploring the motivations and role of farmers in the effective implementation of supply chain sustainability in Ghana and Côte d'Ivoire. *Meridian Institute: Washington, DC, USA*, 1 60.

Schulz, D., & Börner, J. (2023). Innovation context and technology traits explain heterogeneity across studies of agricultural technology adoption: A meta-analysis. *Journal of Agricultural Economics*, *74*(2), 570-590.

Sennuga, S. O., Fadiji, T. O., & Thaddeus, H. (2020). Factors influencing adoption of improved agricultural technologies (IATs) among smallholder farmers in Kaduna State, Nigeria. *International Journal of Agricultural Education and Extension*, *6*(2), 382-391.

Shiekh, R. H. A., & El-Hashash, E. F. (2022). A comparison of the pearson, spearman rank and kendall tau correlation coefficients using quantitative variables. *Asian Journal of Probability and Statistics*, 36-48.

Shin, H., & Antonelli, J. (2023). Improved inference for doubly robust estimators of heterogeneous treatment effects. *Biometrics*, *79*(4), 3140-3152.

Shita, A., Kumar, N., & Singh, S. (2020). The impact of agricultural technology adoption on income inequality: a propensity scores matching analysis for rural Ethiopia. *International Journal of Information and Decision Sciences*, *12*(1), 102-114.

Silvert, C. J., Gusto, C., Warner, L. A., Diaz, J. M., & Mallinger, R. E. (2023). How can residents protect and promote pollinators? The diffusion of residential pollinator-friendly gardening. *Journal of environmental management*, *345*, 118877.

Simtowe, F., Asfaw, S., & Abate, T. (2016). Determinants of agricultural technology adoption under partial population awareness: the case of pigeonpea in Malawi. *Agricultural and Food Economics*, *4*, 1-21.

Soria, S. D. J., Wirth, W. W., & Chapman, R. K. (1980). Insect pollination of cacao in Costa Rica. 1. Preliminary list of the ceratopogonid midges collected from flowers. In: Theobroma v. 10 p. 61-68, 1980.

Sousa, F., Nicolay, G., & Home, R. (2016). Information technologies as a tool for agricultural extension and farmer-to-farmer exchange: Mobile-phone video use in Mali and Burkina Faso. *International Journal of Education and Development Using Information and Communication Technology*, *12*(3), 19-36.

Soviadan, M. K., Kubik, Z., Enete, A. A., & Okoye, C. U. (2022). Assessing the adoption rates of improved technology in traditional poultry farming: Evidence from rural Togo. *African Journal of Agricultural & Resource Economics*, *17*(3).

Sponsler, D. B., Grozinger, C. M., Hitaj, C., Rundlöf, M., Botías, C., Code, A., ... & Douglas, M. R. (2019). Pesticides and pollinators: A socioecological synthesis. *Science of the Total Environment*, *662*, 1012-1027.

Srinika, M., Kumari, R. V., Suhasini, K., & Bhave, M. H. V. (2017). Adoption of integrated farming system-An approach for doubling small and marginal farmers income. *Indian Journal of Economics and Development*, *13*(2a), 443-447.

Suganthy, M. (2019). Survey and monitoring of insect pollinators of cocoa. *International Journal of Farm Sciences*, *9*(3), 4-7.

Suri, T., & Udry, C. (2022). Suri, T., & Udry, C. (2022). Agricultural technology in Africa. *Journal of Economic Perspectives*, *36*(1), 33-56.

Taherdoost, H. (2018). A review of technology acceptance and adoption models and theories. *Procedia manufacturing*, *22*, 960-967.

Tamirat, N., & Abafita, J. (2021). Adoption of row planting technology and household welfare in southern Ethiopia, in case of wheat grower farmers in Duna district, Ethiopia. *Asia Pacific Journal of Science and Technology*, *26*(2), 1-12.

Teka, A., & Lee, S. K. (2020). Do agricultural package programmes improve the welfare of rural people? Evidence from smallholder farmers in Ethiopia. *Agriculture*, *10*(5), 190.

Tesfay, W. (2024). Impact of Improved Coffee Variety Adoption on Coffee Productivity of Smallholder Farmers in North Western Ethiopia. *Journal of Economics and Sustainable Development 14(7):*2023 10.7176/JESD/14-7-03.

Tey, Y. S., Li, E., Bruwer, J., Abdullah, A. M., Brindal, M., Radam, A., ... & Darham, S. (2017). Factors Influencing the Adoption of Sustainable Agricultural Practices In Developing Countries: A REVIEW. *Environmental Engineering & Management Journal (EEMJ)*, *16*(2).

Teye, J. K., Yaro, J. A., & Wiggins, S. (2024). Modernizing cocoa production in Ghana: successes, constraints, and future possibilities of innovation diffusion in the cocoa sector. *African Geographical Review*, 1-14. Anel, A., Kireyeva., Akan, Nurbatsin., G., K.,

Tham-Agyekum, E. K., Awuku, B. O., Ankuyi, F., Appiah, P., Osei, C., De Bakang, J. E. A., & Okorley, E. L. (2024). Dimensions of Accessibility and Use of Information Communication Technology Among Cocoa Farmers in Atwima Mponua District, Ghana. *Journal of Agricultural Extension*, *28*(1), 1-11.

Thornton, P. K., Schuetz, T., Förch, W., Cramer, L., Abreu, D., Vermeulen, S., & Campbell, B. M. (2017). Responding to global change: A theory of change approach to making agricultural research for development outcome-based. *Agricultural Systems*, *152*, 145 153.

Tibesigwa, B., Siikamäki, J., Lokina, R., & Alvsilver, J. (2019). Naturally available wild pollination services have economic value for nature dependent smallholder crop farms in Tanzania. *Scientific reports*, *9*(1), 3434.

Toledo-Hernández, M., Tscharntke, T., Tjoa, A., Anshary, A., Cyio, B., & Wanger, T. C. (2020). Hand pollination, not pesticides or fertilizers, increases cocoa yields and farmer income. *Agriculture, Ecosystems & Environment*, *304*, 107160.

Toledo-Hernández, M., Tscharntke, T., Tjoa, A., Anshary, A., Cyio, B., & Wanger, T. C. (2021). Landscape and farm-level management for conservation of potential pollinators in Indonesian cocoa agroforests. *Biological Conservation*, *257*, 109106.

Toledo-Hernández, M., Wanger, T. C., & Tscharntke, T. (2017). Neglected pollinators: Can enhanced pollination services improve cocoa yields? A review. *Agriculture, ecosystems & environment*, *247*, 137-148.

Tolera, K., & Ballantyne, G. (2020). Insect pollination and sustainable agriculture in Sub Saharan Africa.

Tropenbos International-Ghana. (2018). Learning Lessons from FLEGT-VPA to promote governance reform in Ghana's cocoa sector. Briefing Paper. Tropenbos International.

Ullah, R., Shivakoti, G. P., Kamran, M. A., & Zulfiqar, F. (2019). Land Ownership and Catastrophic Risk Management in Agriculture. *International Journal of the Commons*, *13*(2), 881-891.

Umeh, B. C., Avicor, S. W., Dankyi, E., & Kyerematen, R. (2022). Farmers' knowledge and practices on pollination and insecticide use in cocoa farming in Ghana. *International Journal of Agricultural Sustainability*, *20*(7), 1294-1306.

Uwagboe, E. O., & Agbongiarhuoyi, A. E. (2020). Adoption challenges of Integrated Pest Management (IPM) technology and cocoa production in Cross River state, Nigeria: the elucidation and way forward. *Scientific Papers Series Management, Economic Engineering in Agriculture & Rural Development*, *20*(4).

Uysal, S. D., & Wooldridge, J. M. (2022). Doubly Robust Estimation of Local Average Treatment Effects Using Inverse Probability Weighted Regression Adjustment. *ArXiv preprint arXiv:2208.01300*.

Vanhove, W., Yao, R. K., N'Zi, J. C., Toussaint, L. A. N. G., Kaminski, A., Smagghe, G., & Van Damme, P. (2020). Impact of insecticide and pollinator-enhancing substrate applications on cocoa (Theobroma cacao) cherelle and pod production in Côte d'Ivoire. *Agriculture, Ecosystems & Environment*, *293*, 106855.

Wadud, M. A. (2013). Impact of microcredit on agricultural farm performance and food security in Bangladesh. *Inst Microfinance*, *14*, 47.

Wambua, D. M., Gichimu, B. M., & Ndirangu, S. N. (2021). Smallholder coffee productivity as affected by socioeconomic factors and technology adoption. *International Journal of Agronomy*, *2021*(1), 8852371.

Wanger, T. C., Dennig, F., Toledo-Hernández, M., Tscharntke, T., & Lambin, E. F. (2021). Cocoa pollination, biodiversity-friendly production, and the global market. *arXiv preprint arXiv:2112.02877*.

Warner, L. A., Kalauni, D., Silvert, C. J., Gusto, C., Diaz, J. M., & Daniels, J. (2023). Green industry experts' consensus about wildlife-friendly landscape maintenance: Delphi-informed implications for agricultural and Extension educators. *Journal of Agricultural Education*, *64*(3), 109-134.

Weiner, J. (2017). Applying plant ecological knowledge to increase agricultural sustainability. *Journal of Ecology*, *105*(4), 865-870.

Wilcock, C., & Neiland, R. (2002). Pollination failure in plants: why it happens and when it matters. Trends in plant science, 7(6), 270-277.

Winder, J. A. (1977). Recent research on insect pollination of cocoa. *Bulletin of Entomological Research*, *61*(4), 651-655.

Wongnaa, C. A., Apike, I. A., Babu, S., Awunyo-Vitor, D., & Kyei, A. B. (2021). The impact of adoption of artificial pollination technology in cocoa production: Evidence from Ghana. *Journal of Agriculture and Food Research*, *6*, 100208.

Wongnaa, C. A., Kyei, A. B., Apike, I. A., Awunyo-Vitor, D., & Dziwornu, R. K. (2022). Perception and adoption of artificial pollination technology in cocoa production: Evidence from Ghana. *African Journal of Science, Technology, Innovation and Development*, *14*(6), 1642-1654.

Wordofa, M. G., Hassen, J. Y., Endris, G. S., Aweke, C. S., Moges, D. K., & Rorisa, D. T. (2021). Adoption of improved agricultural technology and its impact on household income: a propensity score matching estimation in eastern Ethiopia. *Agriculture & Food Security*, *10*, 1-12.

Wossen, T., Alene, A., Abdoulaye, T., Feleke, S., & Manyong, V. (2019). Agricultural technology adoption and household welfare: Measurement and evidence. *Food Policy*, *87*, 101742

Wuepper, D., & Finger, R. (2023). Regression discontinuity designs in agricultural and environmental economics. *European Review of Agricultural Economics*, *50*(1), 1-28.

Wurz, A., Grass, I., & Tscharntke, T. (2021). Hand pollination of global crops–A systematic review. *Basic and Applied Ecology*, *56*, 299-321.

Yahaya, A. M., Karli, B., & Gül, M. (2015). Economic analysis of cocoa production in Ghana: the case of eastern region. *Custos e@ gronegócio on line*, *11*(1), 336-352.

Yan, Z. (2020). A basic model of human behaviour with technologies. *Human behaviour and emerging technologies*, *2*(4), 410-415.

Young, A. M. (1982). Effects of shade cover and availability of midge breeding sites on pollinating midge populations and fruit set in two cocoa farms. *Journal of Applied Ecology*, 47-63.

Young, A. M., & Severson, D. W. (1994). Comparative analysis of steam distilled floral oils of cacao cultivars (Theobroma cacao L., Sterculiaceae) and attraction of flying insects:

Implications for a Theobroma pollination syndrome. *Journal of Chemical Ecology*, *20*, 2687-2703.

Yu, B., & Nin-Pratt, A. (2014). Fertilizer adoption in Ethiopia cereal production. *Journal of Development and Agricultural Economics*, *6*(7), 318-337.

Zakariyya, F., Sulistyowati, E., & Rahayu, D. S. (2016). Abundance of pollinator insect (Forcipomyia spp.) of cocoa under some shade trees. *Pelita Perkebunan*, *32*(2), 91-100.

Zegeye, M. B., Fikire, A. H., & Assefa, A. B. (2022). Impact of agricultural technology adoption on food consumption expenditure: evidence from rural amhara region, Ethiopia. *Cogent Economics & Finance*, *10*(1), 2012988.

Zeng, D., Alwang, J., Norton, G. W., Shiferaw, B., Jaleta, M., & Yirga, C. (2017). Agricultural technology adoption and child nutrition enhancement: Improved maize varieties in rural Ethiopia. *Agricultural Economics*, *48*(5), 573-586.

APPENDIX

QUESTIONNAIRES

UNIVERSITY OF GHANA

DEPARTMENT OF AGRICULTURAL ECONOMICS AND AGRIBUSINESS

ADOPTION OF POLLINATION TECHNOLOGY AND ITS EFFECT ON COCOA PRODUCTIVITY

Section A

Farmer characteristics

1. Age: ……yrs [ ]
2. Sex: 0=Female 1=Male
3. Level of education? 0=No education 1=Primary 2=JHS 3= SHS
   4=Tertiary
4. Number of years of schooling completed: …….
5. Marital status? 0=Married 1=Single 2=Widowed
   3=Separated/divorced
6. Ethnicity: ……
7. Religion? 0=Christian 1=Muslim 3=Traditional
8. Is cocoa farming your main source of income? 1=Yes 0=No
9. What other source(s) of income do you have?
10. How many years have you been growing cocoa?
11. What is your household size?

[ ]

12. Are you the household head? 1=Yes 0=No
13. If no to question 12, what is your relationship with the household head? 0=Spouse 1=Child 2= Grandchild Others (specify)
14. Number of household members who are below 18 years: …….
15. Number of household members who are between 18 years and 65 years: ……..
16. Number of household members who are above 65 years: ……..
17. How many adults (18 and above) members of your household work on the farm: ……
18. Source of labour for farming: 0= Family 1=Hired 3 = Communal
19. How did you obtain your farm land: 0=Purchased 1= Lease/rent 2= Family inheritance Other (specify)
20. Do you have access to farm inputs (agro-chemicals)? [ ] 1=Yes 0=No
21. If yes, to question 20, what is your source of input: 0= Purchase 1= Cocoabod support 2= Cocoa licensing company Others (specify)
22. In an average production year do normally you require/ need credit for your farming activities? 1=Yes 0=No
23. During the 2022/2023 production year did you apply for credit for your farming activities? 1=Yes 0=No
24. If you applied for credit in 2022/2023, did you receive it? 0=No 1=Yes, received less than requested amount 2= Yes, received the full amount
25. If yes to question 24, what is the source of credit? 0= Financial institutions 1=Government credit programme 2 = Microcredit scheme 3= Family and friends 4= Others(Please specify)
26. Are you a member of an FBO/CBO? 1=Yes 0=No
27. What is your role in the FBO/CBO 0= Leader 1= Member

<u>Section B</u>

Farm characteristics

28. How many cocoa farms do you have?

29. Kindly provide the following

Farm(s)	Farm Size (Ha)	Age of cocoa farm (yrs)
1		
2		
3		
4		
5		

30. Do you know how cocoa is pollinated? 1=Yes 0=No

31. If yes to question 28, how is cocoa pollinated? …….

32. Have you heard of cocoa pollinator technology (practice of breeding for insect pollinators on cocoa farm)? 1=Yes 0=No

33. If yes to question 30, do you practice pollinator technology on your cocoa farm(s)?
    1=Yes 0=No

34. If no to question 31, why? Please give reason(s)……

35. If yes, to question 31, on how many of your cocoa farm(s) do you practice pollinator technology?

36. What is the total farm size used for practicing pollinator technology?

37. Which material(s) do you use for the pollinator technology:

0 =Cocoa pod husks 1= banana/plantain pseudo stem 2=Cocoa leafs Others(specify) (NB: Multiple answers are allowed)

38. Which of the pollinator technology type(s) do you practice on your cocoa farm

0=Heaping of cocoa pods 1= Using dug holes 2= Moveable containers

39. How do you manage cocoa pod husks on the farm? (NB: Multiple answers are allowed)

Heaping [ ] Dug holes [ ] Spreading [ ] Other (specify).

40. How many heaping sites do you have on your cocoa farm(s)?

41. How many dug hole sites do you have on your cocoa farm(s)

42. How did you hear/know about pollinator technology? (NB: Multiple answers are allowed)

Extension services [ ] Media [ ] Observed other farmers adopting it [ ]

Recommendation from family members, friends and neighbors [ ]

43. Have you received training on pollinator technology? 1=Yes 0=No

44. Who organized the training? 1= Extension agents 2= NGO 3= Licensing buying company

45. How many days was the training?

46. How many years have you been practicing pollinator technology on you cocoa farm(s)?

47. Do you apply agro-chemicals on the pollinator technology farm(s)? 1=Yes 0=No

48. If yes to question 45, do you always apply per the required dosage/quantity? 1=Yes 0=No

49. Do you mix different agro-chemicals during spraying? 1=Yes 0=No

Section C

Perception on pollinator technology

50. Indicate the extent of your agreement with the following statement by ticking the corresponding column of response: 1=strongly disagree, 2= disagree, 3=neutral, 4=agree, 5=strongly agree

Statement	**1**	**2**	**3**	**4**	**5**
Perceived Benefits					
a. Pollinator Technology leads to improved soil nutrients					
b. Pollinator Technology is not affected by agro-chemicals					
c. Pollinator Technology is simple and easy to practice					
d. Pollinator Technology improves cocoa yields					
e. Pollinator Technology increases profit					
f. Pollinator Technology requires less labour					

g. GAPs can be practiced on a Pollinator Technology farm					
Perceived Cost					
h. Pollinator Technology is costly to practice					
i. Pollinator Technology makes weeding on the cocoa farm difficult					
j. Pollinator Technology requires more tools/equipment					
k. Pollinator Technology increases cost of inputs (agro-chemicals)					
l. Pollinator Technology increases cost of labour					
Perceived environmental effects					
m. Pollinator Technology					

increases the incidence of pests and diseases on the cocoa farm					
n. Pollinator Technology reduces toxicity and residue in the environment					
o. Pollinator Technology is environmentally friendly					

Section D

Impact of Pollinator technology

51. How many kilos did you harvest during the 2022/2023 season?
52. How many kilos of after using pollinator technology in the 2022/2023 season? …….
53. What was the price per kilo of cocoa bean? …………
54. What was your estimated annual income from sales of cocoa beans in 2022/2023: Ghs …
55. What percentage of the income was consumed by the household? ……
56. What percentage of the income was used for the cocoa farm: …?
57. What percentage was put into savings: …...
58. What was the estimated income from other farming produce aside cocoa
59. What was the cost for producing a hectare of cocoa as per the following;

Item	Quantity/acre	Unit Cost (Ghs)	Total Cost (Ghs)
Inputs			
Cocoa seedlings			
Farm tools/machines			
Fuel for machine(if any)			
Oil for machine (if any)			
Agro-chemicals			
Insecticides			
Fungicide			
Liquid fertilizer			
Granular fertilizer			
Labour			
Weeding of cocoa farm			
Spraying of cocoa farm			
Pruning of cocoa farm			
Harvesting of cocoa pods			
Breaking of cocoa pods			
Carriage of fermented cocoa beans to drying mat			

Section E

Constraints/Challenges associated to pollinator technology

60. Kindly identify and rank the constraints/challenges associated with pollinator technology. Rank from 1-8, with 1 being the most severe constraint and 8 the least.

Constraints	Tick	Rank (from 1-8)
1. Inadequate information about Pollinator Technology		
2. Lack of training on Pollinator Technology		
3. Difficulty in managing Pollinator technology		
4. Low pods sets on pollinator technology farms		
5. Seed quality is low on pollinator technology		

farm		
6. Pollinator Technology is costly to adopt		
7. Pollinator Technology is labour intensive		
8. Inadequate technical knowledge on pollinator technology		

Thank you

Over identification balance test

```
Overidentification test for covariate balance
H0: Covariates are balanced

        chi2(10)     =   6.9081
        Prob > chi2  =   0.7341

. teffects overlap

. tebalance summarize

Covariate balance summary
```

	Raw	Weighted
Number of obs =	396	396.0
Treated obs =	188	197.8
Control obs =	208	198.2

	Standardized differences		Variance ratio	
	Raw	Weighted	Raw	Weighted
Total_farm_size	.0051906	.0289756	.8811677	.9447211
Age	.0619791	-.026895	.947895	.878012
years_schooling	-.0398049	.0238307	1.252854	1.211412
experience	.1124154	-.0629175	.7269818	.5603215
householdsize	-.0642434	.0023838	1.295181	1.238013
edu_dummy	.0743825	-5.84e-06	.9949658	1.000012
AEAs	.2027499	.0156636	.9033572	.9889795
Training	-.0591868	.0069439	.9331144	1.008864
marri_status	.232503	-.0119296	1.661529	.9990314