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Original Article

Impact of Different Agro-Forestry Systems on Cocoa Diseases among Smallholder Farmers in Bundibugyo District – Western Uganda

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ABSTRACT

The Cocoa Agroforestry system integrates cocoa with high-value tree species and crops, providing additional income for farmers. In the Bundibugyo district, where cocoa is a primary livelihood, recent declines in cocoa production have been linked to diseases. This study evaluated the impact of various Agroforestry systems on cocoa diseases among smallholder farmers in Bundibugyo. Data were collected from four administrative units using a cross-sectional design with purposive sampling of 92 respondents. Household interviews, questionnaires, photographs, data sheets, and observations enriched the study. Findings revealed no correlation between Black Pod disease and Cocoa Agroforestry systems. However, Witches' Broom and Frost Pod Root diseases significantly influenced cocoa production, while Cocoa dieback showed no significance. Cocoa diseases were more prevalent during the rainy season (72%), followed by the dry season (26%), and year-round (7%). Shade diversity impacted disease incidence, with medium shade systems (shade diversity 2-3) experiencing the highest disease impact (90%) compared to lower diversity systems (9%). Additionally, cocoa pod borer was identified as a significant pest, while cocoa pod rot emerged as a major disease. The study highlights the critical influence of specific agroforestry practices and shade diversity on managing cocoa pests and diseases in Bundibugyo.

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INTRODUCTION

Agroforestry is not a new or revolutionary farming method. It is one of the oldest agricultural production methods (Sudomo *et a*l., 2023). Cocoa agroforestry entails growing cocoa together with shade trees and food crops for agronomic, economic and environmental benefits (*Ecosystem Services in Fine Flavor Cocoa Agroforestry Systems from Ecuador*, 2019). Cocoa agroforestry is thus part of a larger trend to encourage forestry as a tool for climate change mitigation and adaptation. Cocoa agroforestry systems are in diverse categories and this study focused on the numbers of different tree species shade tree diversities) on a particular cocoa farm and their association with disease incidences (Shinyekwa *et al*., 2017).

Agroforestry systems are land management practices that integrate trees and shrubs into agricultural landscapes, combining the benefits of agriculture and forestry to create more diverse, productive, and sustainable land-use systems and these systems are designed to optimize the interactions between trees, crops, and livestock, improving overall land productivity, soil health, water management, and biodiversity (Olwig *et al*., 2023). Bundibugyo district is known for practising an array of agroforestry systems, which is the growing of trees and crops for commercial utilization and utilization of natural resources (Kassa, 2008; Hernández-nuñez *et al*., 2024).

Silvopasture, integrating trees with pastureland, where livestock graze among trees. This system improves animal welfare and productivity while providing timber and other tree products. Alley Cropping: Planting rows of trees or shrubs with crops grown in between. This enhances crop yield, improves soil health, and provides tree products. Forest Farming, growing high-value specialty crops under the protection of a forest canopy. This includes medicinal plants, mushrooms, and shade-tolerant crops. Windbreaks/Shelterbelts, planting rows of trees or shrubs to protect crops and livestock from wind. This reduces soil erosion and protects crops from damage. Riparian Buffers, planting trees and shrubs along waterways to protect water quality by reducing runoff and erosion. Home gardens, small-scale agroforestry systems around homes, integrating a variety of plants, trees, and sometimes livestock. This promotes food security and biodiversity (Vanoverschelde, 2023).

Thus far, research on cocoa agroforestry is generally positive regarding its potential to increase farms' resilience to climate change while providing additional, diversified and more stable incomes, enhancing biodiversity, supporting healthy ecosystems and reducing the pace at which farms expand into forested areas (Olwig *et al*., 2023; Shinyekwa *et al*., 2017). Furthermore, shading trees can be maintained in cocoa-based agroforestry systems to reduce pest attacks (Rahim Foroughbakhch *et al*., 2010) and stabilize the microclimate (Vanoverschelde, 2023), providing soil protection against raindrops (Olwig *et al*., 2023). Scientific literature shows a consensus that cocoa-based agroforestry systems with dense and diverse shade trees stand to harbour high levels of species richness (Vanoverschelde, 2023). The primary aim is not only to sustain forests in cocoa-growing areas but also to increase the income of small-scale cocoa farmers (Shinyekwa *et al*., 2017). Production technologies such as canopy and weed management, along with disease control, were developed to address farmers' production problems, leading to a considerable increase in cocoa production (Hernández-nuñez *et al*., 2024).

In related studies, tree planting is a key objective to improve food security, environmental

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conservation, and the well-being of African rural households through agroforestry (Jones *et al*., n.d; Richard, & Ræbild, 2016). This is achieved directly through various types of edible and medicinal plants, wood, and other non-timber products, and indirectly through the sustainable provision of environmental services such as carbon sequestration and storage by woody components (cocoa, fruit trees, forest trees) in cocoa-based agroforestry, as well as disease and pest control (Bwambale *et al*., 2021). Different disease incidences vary according to farming systems. Attention is drawn to evaluating cocoa diseases in a cocoa tree shade system to develop a better and more sustainable system for cocoa production while protecting the environment and conserving biodiversity (Hernández-nuñez *et al*., 2024).

LITERATURE REVIEW

Shade trees are trees that with their applications, crops are purposely raised under tree canopies and within the resulting shady environment. For most uses, the understory crops are shade tolerant or the over-storey trees have fairly open canopies a conspicuous example is the grown cocoa. This practice reduces weeding costs, and mired attacks in cocoa and increases the quality and taste of the cocoa (NGALA, 2015).

Agro-forestry is defined as the combination of forest trees with crops, domestic animals, or both (Kellimore, 2010). Agro-forestry is a land use management system in which trees or shrubs are grown around or among crops or pastureland. It combines agricultural and forestry technologies to create more diverse, productive, healthy, and sustainable land-use systems (NGALA, 2015).

Agro-forestry systems include both traditional and modern land-use systems where trees are managed together with crops and animal production systems in agricultural settings. The presence of trees on external and internal boundaries, cropland, homestead plots or any other available niche of farmland, defines the Agroforestry systems structurally (Kakhobwe *et al*., 2010).

Deforestation is defined as the conversion of forest to another land use or the long-term decline of forest cover below the minimum threshold of 10% (FAO, 2006). Its causes are many and vary from one country to another with some examples like pressure, poverty and Agriculture (NGALA, 2015).

Forest Degradation is a process of change within the forest that negatively affects its characteristics (Kakhobwe *et al*., 2010). It also refers to the reduction of the capacity of a forest to produce goods and services. Capacity includes maintaining the structure and ecosystem functions. A degraded forest provides only a limited amount of goods and services and maintains only limited biological diversity. It lost its structure, function, species composition and productivity normally associated with natural forests (Kellimore, 2010)

Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Olwig *et al*., 2023)

The cocoa tree (*Theobroma cacao L.*) is a forestry tree which produces fruits for commercial purposes. It originated from South America and is highly valued for its beans, which are used to produce cocoa powder and butter. In recent years, global cocoa production has tripled, reaching a record 3.7 million tons of dry cocoa beans in 2008 and generating an estimated US$7.4 billion in income for millions of smallholder farmers (Rajab *et al*., 2016). Cocoa beans are cultivated worldwide, with several countries in South America contributing significantly to production: Brazil (256,186 metric tons), Ecuador (128,446), Mexico (82,000), Peru (71,175), Dominican Republic (68,021), Colombia (46,739), Papua New Guinea (41,200), and Venezuela (31,236; Ikendi *et al*., 2024).

In Africa, cocoa is predominantly produced in tropical zones near the Equator, where climatic

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conditions favour cocoa tree growth (Bertsch-h, 2021). Approximately 70 percent of the world's cocoa beans come from four West African countries: Ivory Coast, Ghana, Nigeria, and Cameroon (Shinyekwa *et al*., 2017; Owino, 1992). Ivory Coast and Ghana are the largest producers, accounting for over 50 percent of global cocoa production. In 2016, the Ivory Coast alone produced approximately 1.6 million metric tons of cocoa beans (Petithuguenin, 2000; Wahyudi, & Coffee, 2008).

Uganda produces 26,000 metric tons per year, with more than 14,000 hectares of cocoa planted in smallholdings in various regions including Mukono, Bundibugyo, Buikwe, Kibaale, Kasese, Jinja, Kamuli, Iganga, Hoima, Mpigi, and Luwero (Hernández-nuñez *et al*., 2024). In the Bundibugyo district, by 1978, two fermenters were established at Bubomboli and the district headquarters. According to statistics from the commercial office, over 85% of the population in Bundibugyo district is directly dependent on cocoa, producing approximately 18,000 metric tons, as reported by the District Production Officer (Vanoverschelde, 2023).

Cocoa Origin and Distribution

Cocoa is a perennial crop that responds well in rainy tropical areas, with a maximum annual average of 30-32ºC. It thrives under shades and in areas with annual rainfall between 1,500mm to 2,000mm. According to the International Cocoa Organization, it grows in countries lying between 10ºC north and 10ºC south of the equator. It does well in soil containing coarse particles with a reasonable quantity of soil nutrients to a depth of 1.5m to allow the development of a good root system (Mkandawire & Soludo, 2003).

The genus *Theobroma* originated from the Amazon and Orinoco basins and subsequently spread to Central America, particularly Mexico, where it was known and used by the local population. The Olmec and Mayas, and later the Toltecs and Aztecs considered it the "food of the gods" (Wessel, & Quist-Wessel, 2015). In the 16th century, Spanish explorers were the first to bring cocoa beans to Europe. Nowadays, cocoa has become one of the most important cash crops and is a key ingredient for many sweets and cosmetics. Since the discovery by Europeans, the tree quickly spread and became important throughout the humid tropics (Wahyudi et al., 2008).

Theobroma has been divided into twenty-two species of which T. cocoa is the most widely known. It was the Maya who provided tangible evidence of cocoa as a domesticated crop (Petithuguenin, 2000). Archaeological evidence in Costa Rica indicates that cacao was drunk by Maya traders as early as 400 BC. The Aztec culture, dominant in Mesoamerica from the fourteenth century to the conquest, placed much emphasis on the sanctity of cocoa. The first outsider to drink chocolate was Christopher Columbus, who reached Nicaragua in 1502 searching for a sea route to the species of the East. But it was Hernan Cortes, leader of an expedition in 1519 to the Aztec empire, who returned to Spain in 1528 bearing the Aztec recipe for *xocoatl* (chocolate drink) with him. The drink was initially received unenthusiastically and it was not until sugar was added that it became a popular drink in the Spanish courts (Rifin, 2013).

COCOA PLANT DESCRIPTION

Theobroma cacao belongs to the plant kingdom, *mangnoliophyta* division in the *mangnoliopsida* class, under the *malvale* order in the family *malvaceaes* (Aikpokpodion, 2012) cacao types are classified into three main groups: Criollo, Forastero and Trinitario. Criollo cacao developed in Northern South America and has thin walls and red or yellow fruits. The seeds are large, round, white or pale purple, not astringent, and produce the highest quality chocolate. (Wessel and Quist-Wessel, 2015) Unfortunately, Criollo types are low-yielding, susceptible to many diseases and are rare in cultivation. Forester cacaos are from the Amazon basin and have a thick wall, smooth and usually yellow fruit. The seeds are flattened and purple in colour.

Forastero cacaos are very productive and dominate the world of cacao production. Trinitario cacao arose in Trinidad as hybrids of Criollo and Ferastero type. They are highly

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variable and considered high quality for chocolate production (Wessel and Quist-Wessel, 2015). There are approximately 22 Theobroma species, and about 15 are utilized for their edible pulp or seeds. Theobroma cacao is the most important species within the genus *theobromae*. *Theobroma grandiflorum* (cupuassu), *Theobroma gileri* (mountain cocoa), *T*, *bicolor* (macambo) and *T. subincanun* (wild cocoa) are other species utilized for their sweet, edible pulp and edible seeds. (Wessel and Quist-Wessel, 2015).

The cocoa plant is a medium-sized tree, reaching 20-30 feet (4-8m) tall. Branches are produced in groups of three to five. The leaves are simple, 4-8 inches (10-20 cm) long, light to dark green and soft and flexible. New growth is bright red or pink. Small whitish flowers are produced on the branches and trunk, singly or in groups of 3-5. Fruits are 5-10 inches (13-26 cm) in length and 2-3 inches (5-7.6) in diameter. The fruit has a hard shell which may be smooth or ridged, elongated or rounded, red, yellow, or orange, and contains between 20-50 seeds, surrounded by a cream-coloured, sweet-sour, aromatic pulp (Mkandawire & Soludo, 2003)

The original habitat of the cocoa plant is the tropical forest with a canopy of tall trees, rainfall and humidity are high, so the plants grow tall. In the garden, plant height at 3 years can reach 1.8-3 meters and at the age of 12 years reach 4.5-7 meters (Andres, C., & Bhullar, G.S., 2016) Cocoa plant is dimorphs (two forms have branches), that is, orthotropy branches (branches that grow upward) and plagiotropic (branches that grow sideways) (Nomo B, 2005). Cocoa is a plant with a feeder root surface (mostly developing lateral roots near the surface). The thickness of the rooting zone in good soil is 30-50 cm. In low soil water soils, roots grow long and ride the lateral roots into the soil, whereas in high-soil water and clay soils, the roots do not grow up riding so deep and lateral roots grow near the soil surface (Arnó *et al*., 2012)

Cocoa Ecology

Mean minimal temperatures of less than 21 degrees C are not suitable for cocoa cultivation (Braudeau, 1969). Average rainfall of 1250-3000m per annum and preferably between 1500-2000 m with a dry season of not more than three months with less than 100 mm rain per month is ideal but the quantity is less important than the distribution. Rainfall can be supplemented with irrigation during dry months. Temperature varies between 30-32degrees c mean maximum and 18-21degrees c mean minimum but around 25degrees c is considered to be favorable.

Humidity is uniformly high in cocoa growing areas, often 100% at night falling to 70 or 80% by day times during the dry season. The larger and greater leaf area than plants growing at medium (70-80%) and high (90-95%) humidity under the letter conditions leaves tend to be curled and withered at the top. The other effect of humidity concerns the spread of fungal diseases and the difficulties of drying and storage. Cocoa is a tap-rooted plant and is grown on a wide range of soil types and the standards for soil suitable for cocoa vary considerably. The best soil for cocoa is that which is rich in humus, deep well-drained soils free from iron concentrations and high in nutrient content (Opeke, 2005; Onakoya, 2012).

The cocoa tree is a shrub undergrowth native to the Amazon rainfall rainforest and can grow well in a very dense shade. It is now shown that shading is a limiting factor of production and should be maintained to pass more than 50% of light (Mossu *et al*., 1990).

Cocoa Seed Production

Cocoa seeds readily germinate when sown and do not pass through a dormancy period. For raising seedlings, the seeds of mature pods are taken from high-yielding mother plants. The mother plants selected should have medium or large green pods with an average dry bean of not less than one gram. A more suitable procedure for planting good quality seedlings is to collect hybrid seeds from biclonal or polyclonal seed gardens involving superior self-incompatible parents (Onakoya, 2012). They lose viability on extraction from the pod within five to seven days unless specially treated. Cocoa seeds are therefore best stored in pods whereby they remain viable for

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up to four weeks after harvesting. If it is therefore necessary to extract the seeds from the pods for storage, the extracted seeds should be mixed with moist fine sand, moist sawdust or moist ground charcoal. The mixture should therefore be stored in a cool dry place and under such conditions; extracted seeds can be stored for two to three weeks (Onakoya, 2012).

Cocoa Diseases

Witches' Broom

Taphrina betulina is a fungus responsible for Witches' Broom disease. During the last century, the fungus spread throughout all of South America, Panama and the Caribbean, causing great losses in production. The most visible effect can be seen in Brazil where the introduction of the disease in the region of Bahia caused a decrease in production of almost 70% during a period of 10 years (Roberts & St Leger, 2004). The fungus attacks only growing tissues that is, shoots, flowers and pods causing cocoa trees to produce branches with no fruit and ineffective leaves. The pods show distortion and present green patches that give the appearance of uneven ripening.

Witch's Broom disease, caused by the fungus *Moniliophthora perniciosa*, affects growing tissues such as shoots, flowers, and pods, resulting in cocoa trees producing branches with no fruit and ineffective leaves, along with distorted pods showing green patches Wessel, & Quist-Wessel, (2022). The life cycle of the fungus is synchronized with the phenology of the host. One of the most influential factors for the adequate reproduction of the fungus is water. Basidiospores released at night are related to the level of humidity of about 80% and favourable temperature comprised between 20 and 30 degrees C. The spores are capable of being disseminated locally by water and convection currents and over long distances by wind. Host resistance is recommended as the best option for economic and sustainable control.

Frosty Pod Rot

Is caused by the basidiomycete *Moniliophthora roreri* which is found in all north-western countries in South America. The first reports of the disease date back to the end of the 19th century, when its aggressive effects caused devastation in Colombian and Ecuadorian cocoa plantations. The fungus has now spread all over the Latin America region, causing significant losses in production, even resulting in the abandonment of cocoa farms (Wessel, & Quist-Wessel, 2015). The fungus infects only actively growing pod tissues, especially young pods. The time from infection to the appearance of symptoms is about 1-3 months. The most outstanding symptom is the white fungal mat on the surface. The large number of spores produced (44 million spores per cm) and the genetic variability endow the fungus with spores' considerable adaptability (Taylor et al., 1999; Adejumo, 2005).

Frosty Pod Rot, caused by the Basidiomycete *Moniliophthora roreri,* has been devastating cocoa plantations since the late 19th century due to its aggressive effects Wessel, & Quist-Wessel (2022). The dry, powdery spores allow the fungus to be dislodged by water, wind or physical disturbance of the pod. Disease incidence varies with cultivar, pod age and rainfall. Generally, the greatest production is when rainfall is high. All cocoa species seem to be susceptible to this disease. The use of copper and organic protectors has proved to reduce the incidence of the disease. Systematic fungicides such as Flutolanil have been found effective, although the use of agrochemicals is not economically sustainable given the cocoa (Adejumo, 2005)

Phytophthora Pod Rot

It's also known as Black Pod, is caused by the fungus *Phytophthora spp.* Three fungal species of the same genus are responsible – *P. palmivora*, *P. megakarya* and *P. capsici*. Megakarya causes global yield loss of 20 -30% and tree deaths of 10% annually. *P. megakarya* is the most important pathogen in central and West Africa, known as the most aggressive of the Pod Rot pathogens. *P. capsici* is widespread in Central and South America, causing significant losses in favourable environments (NGALA, 2015)

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One major difference between *P. palmivora* and *P. megakarya*, is the damaging species on cacao, the production, maturation, and liberation of sporangia are grouped in a short period *for P. palmivora*, and in an extended period for *P. megakarya* (Wessel, & Quist-Wessel, 2015). On a single cocoa pod, zoospores can be released from sporangia for over 30 days when infected by *P. megakarya* (NGALA, 2015) Based on this basic difference between the two species, we strongly believe that an effective screening strategy for biocontrol candidates of *P. megakarya* needs to lay emphasis on endophytic strains that could control the production and maturation of sporangia on cocoa pods since sporangia and, in turn, zoospore are the major propagules for the dissemination of this fungal disease.

Several diseases are common in cocoa production in Uganda, particularly in Bundibugyo. *Phytophthora* Pod Rot, also known as Black Pod, caused by the fungus *Phytophthora spp*., results in global yield losses of 20-30% annually and tree deaths of 10%, particularly in favourable environments (Vanoverschelde, 2023).

Vascular-Streak Dieback (VSD)

This was distinguished from the various dieback syndromes of cocoa induced by environmental factors and insects in Papua New Guinea (PNG) IN THE 1960S (Wessel and Quist-Wessel, 2015). It caused heavy losses of mature trees and seedlings planted near older cocoa. The disease was later shown to be caused by a new genus and species of basidiomycete, *Oncobasidium theobromae*. VSD has since been found in most cocoa-growing areas in South and Southeast Asia and PNG, from New Britain in the east to Hainan Island. Dieback disease causes significant losses in mature trees and seedlings planted near older cocoa trees. It has been a major problem in large commercial plantations in Uganda, as well as in other countries like West Malaysia and Sabah (Wessel & Quist-Wessel, 2022).

COCOA SHADE TREES

Cocoa (*Theobroma cacao L.*) landscapes in West and Central Africa consist of a mosaic of smallholder cocoa farms that range in their structural diversity and species richness between highly diverse cocoa Agro forests like those encountered in southern Cameroon (Nomo, 2005; Sonwa *et al.*, 2007) and cocoa monocultures, which exist in parts of Ghana and Côte d'Ivoire (Owino, 1992). Tree diversity in cocoa farms offers farmers a range of agronomic, economic, cultural, and ecological benefits (Rice, & Greenberg 2000; Di Falco, & Perrings,2003; Somarriba, & Beer, 2011). However, the composition and structure of shade tree stands in mixed systems have been reported to also cause excessive shade, which can lead to high humidity and create favourable conditions for black pod diseases in cocoa systems (Dakwa, 1976; Opoku *et al*. 2002) and also affect the mechanisms that drive fruit losses on cocoa trees (Bos *et al*., 2007).

Shade trees play a crucial role in cocoa production by enhancing production, controlling diseases, preserving biodiversity, and conserving the environment. Specific trees, such as palm trees commonly grown alongside cocoa plantations in countries like Ghana and Uganda, along with multipurpose trees like umbrella tree musizi (*Maesopsis eminii,)* coconut (*Cocos nucifera*), neem (*Azadirachta indica*), mangoes (*Mangifera indica*), tamarind (*Tamarindus indica*), jackfruit (*Artocarpus heterophyllus*), and avocado (*Persea americana*), are grown for shade and fruits for home consumption (Olwig *et al*., 2023)

There has been limited research on cocoa shade trees and their association with diseases. Therefore, the main objective of this study was to identify Agroforestry systems with the potential to reduce disease constraints in cocoa farms. Specifically, the study aimed to determine the influence of shade tree species diversity on disease incidence in cocoa. Having examined the three shade systems (heavy, Medium and light shade systems) (Sudomo *et al*., 2023).

Utilization of Cocoa Beans

The main constituents of the cocoa bean are cocoa fibre, cocoa butter and the shell. These are separated during industrial processing. The fat-free fiber contains about 3% of theobromine

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which can be converted into caffeine. In the manufacturing of chocolate, the roasted nibs are ground into a mass to which extra cocoa butter is added along with other ingredients mainly sugar. In the making of milk chocolate, milk solids are added to the mass. Cocoa butter which constitutes some 56% of food cocoa beans is a high-grade vegetable fat with several valuable virtues. It melts at body temperature; it has good keeping qualities; it does not readily develop free fatty acids and it is readily digestible and agreeable to the palate. (Olga Rojo-Poveda et al., 2020).

Its aromatic properties and other qualities are not readily reproduced and there is a limit to the use of cocoa butter substitutes. The cocoa bean, therefore, constitutes the raw material of important industries which manufacture. Semi-finished products intended for other industries, like cocoa mass used for making chocolate, biscuits and confectionery; melted cocoa intended for various food industries or sweet products; and cocoa butter used in making sweets, chocolate, perfume and other cosmetics and pharmaceutical preparations (Wessel, & Quist-Wessel, 2015).

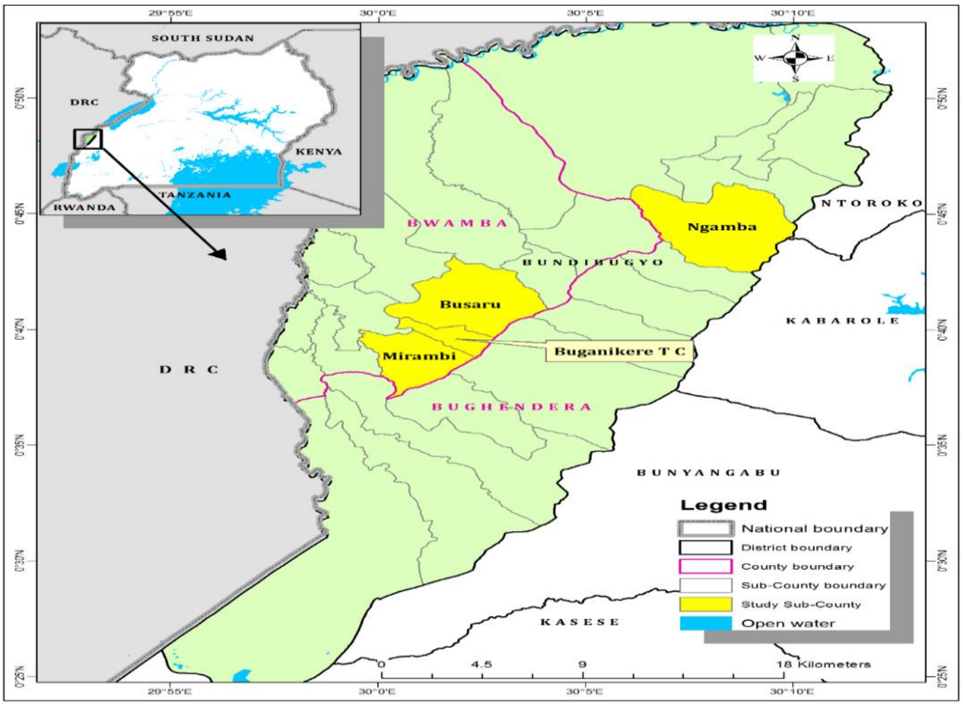
Finished products intended for direct consumption such as chocolate powder, bars and chocolate confectionery. Olga Rojo-Poveda et al. (2020) document that apart from soft drinks which have a larger market than confectionery; confectionery is far bigger than any other food or beverage category in terms of market value/retail selling prices. By-products of this industry such as husks, fats extracted from husks and germs are used to feed cattle, manufacture fertilizer, pharmaceutical products and soap.

METHODOLOGY

Study Area

The Bundibugyo community is primarily agrarian, with an estimated population of approximately 30,000 people and a population density of 150 individuals per square kilometre. The district comprises a variety of inhabitants who are sociologically divided into three main groups, each led by a traditional chief: The Bamba/Babwisi group, the Bakonzo group, and the Batwa group. Besides, all these groups practice the same cocoa agroforestry systems of alley which is the growing of trees and crops for production by utilizing natural resources. The study took place in four sub-counties, Busaru, Ngamba, Mirambi and Buganikere Town Councils respectively (Figure 1).

Figure 1. A Map Showing the Study Area.



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Study Design

The research employed a mixed approach design, allowing data collection at various points in time. The researcher utilized both quantitative and qualitative methods, with the quantitative aspect used to quantify results through measures like central tendency, correlation, and regression techniques, while the qualitative aspect aimed to provide explanations for observed phenomena.

The study was non-experimental and focused on addressing specific objectives. Various methods of data collection, including interviews, photography, observations, and questionnaires, were utilized based on the relevance of each variable under investigation.

Sampling Procedure:

For both qualitative and quantitative data, 92 respondents were selected, judgmentally based on their experience and farm size, and selected through referral by the initial respondents (Chain referral or snowball sampling), as suggested by other scholars who stated that saturation is typically reached by the fourth respondent. The chain referral was supplemented by using the formula: n = N / (1 + Ne^2) where N is the total population, n is the sample size, and e is the marginal error (5% or 0.05, since the study is conducted at a 95% level of significance), the sample size was calculated to be 92 respondents.

Sampling Technique:

Purposive sampling was employed to select the sub-counties where the study was conducted. Four sub-counties with predominantly smallholder cocoa farmers were purposively sampled from the 20 sub-counties in Bundibugyo district. Within each sub-county, a list of households was obtained from the sub-county records, and respondents were selected using simple random sampling, where each household had an equal chance of being chosen. Random numbers generated using Excel were utilized for household selection.

Data Collection

The study utilized a variety of data collection methods including questionnaires, interviews, observations, and photography. Given that the objectives were qualitative, surveys were conducted using purposive sampling, and a systematic approach at different stages of data collection. Questionnaires were administered to farmers who filled them out with guidance from the researcher. This tool captured information on the types of diseases and their prevalence in different agroforestry systems. Each farmer within the determined sample size was required to complete the questionnaire. Questionnaires were chosen for their ability to gather extensive data and provide respondents with multiple options for their responses. Additionally, the questionnaires were supplemented with photographs depicting specific diseases and pests to facilitate accurate information retrieval from respondents.

Observations; specifically, were used to observe diseased cocoa plants in the cocoa plantations based on the internationally accepted disease and pest signs to enrich the report and this paper as well. Photography; photos of diseased cocoa plants were captured to provide evidence of the diseased cocoa plantations but also were used for visibility purposes and adding value to this article. Interviews were conducted while filling in the questionnaires at the farm level with respondents. Data sheets were used to record differences in cocoa bean traits from two systems of farming with the aid of observation.

RESULTS AND DISCUSSIONS

Results

Table 1. Respondents' Demographic Data

Sex		Age			Education			Acreage		Cocoa age		
M	F	20-35	36-55	56+	Pri	Sec	Tert	1-2	3-5	10-15	16-21	22+
71	11	15	50	17	20	41	21	34	48	21	31	30

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Table 1 summarizes the demographic data in terms of education status, age, sex segregation, cocoa age and acreage which include gender, age, education status, acreage and cocoa age.

Influence of Shade Tree Diversity on Disease Incidence

A summary of infection and association trends of disease incidences with different tree species are provided in Table 3. Agroforestry systems were categorized based on respondents' plantations as follows: shade diversity 1 (one shade tree species), shade diversity 2 (two shade tree species), shade diversity 3 (three shade tree species), shade diversity 4 (four shade tree species), shade diversity 5 (five shade tree species), and shade diversity 6 (six shade tree species). Different diseases had varying incidence levels across diversities, as depicted in Table 3. For instance, Black pod rot disease affected all farms at 100% regardless of the shade diversities present. This disease showed unique characteristics compared to other diseases, as it did not appear to be correlated to any shade tree diversities, with no farm found free from the disease incidence (Figure 2).

Table 2: Disease Association with Specific Shade Tree Species

Tree species	Witch's	Frost Pd	Swollen	Dieback	Tree species	Witches	Frost Pd	Swollen	Dieback
Maesopsis eminii	**55.41*** **	**25.90*** **	**31.55*** **	**52.73*** **	***Eucalyptus globulus***	**16.71*** **	**6.76*** **	**14.52*** **	**25.01*** **
Markhamia Obtusifolia	**3.95****	**2.04**	**0.38**	**3.53**	***Pinus sabiniana***	**0.79**	**0.41**	**0.08**	**0.78**
Schefflera Actinophylla	**4.32***	**2.23**	**1.7**	**4.24***	***Arecaceae***	**2.76**	**0.08**	**2.62**	**2.13**
Cinnamomum tamala			**19.22*** **	**8.07*** **	***Ficus capensis***	**0.53**	**0.27**	**0.06**	**0.51**
Artocarpus heterophyllus	**2.65**	**0.01**	**1.93**	**1.15**	***Psidium guajava***	**0.52**	**0.27**	**0.06**	**0.51**
Triplochiton seleroxylon	**0**	**0.71**	**0.8**	**0**	***Citrus X sinensis***	**5.19**	**3.09**	**1.51**	**5.28**
Persea Americana	**9.79*** **	**3.83**	**11.47*** **	**14.10*** **	***Aleurites moluccanus***	**2.58**	**1.32**	**7.21*** **	**2.86**
Albizia glaberrima	**0.26**	**1.13**	**1.44**	**0.25**	***Spathodea campanulate***	**0.26**	**0.31**	**0.71**	**0.23**
Glicidia sepium	**1.36**	**0.55**	**2.2**	**1.33**	***Morinda lucida***	**0.52**	**0.27**	**0.45**	**0.51**
Mangifera indica	**6.46***	**4.85***	**1.02**	**5.54***					

***, ** and *** stand for significance at 5, 1 and 0.1% error margins respectively**

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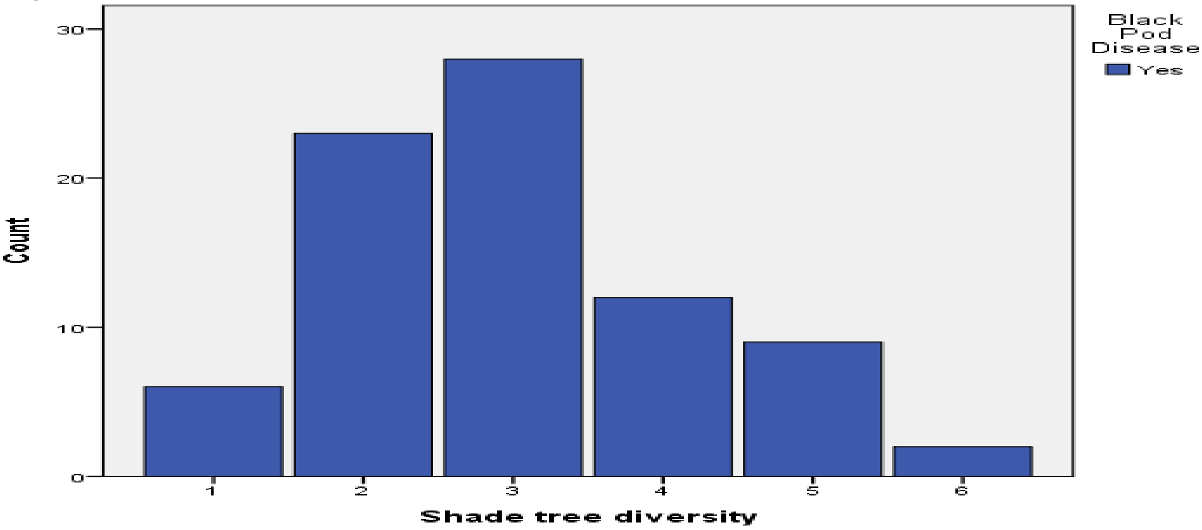
Cocoa pod rot disease Cocoa dieback disease Blasio & team

The photos above were captured on cocoa farms for cocoa pod rot and cocoa wilt (dieback disease). The detailed information about these specific diseases is narrated in the figures below.

Figure 2. Incidence of Black Pod Rot Disease.



Source: *Primary data (2021):*

Witches broom disease exhibited positive results (non-significant) in relation to shade diversities, with some degree of control observed, particularly at shade diversity. However, at shade diversities 5 and 6, only infected cases were registered, indicating a potential need for specific limited tree species to be inter-planted with cocoa for shade and better disease management.

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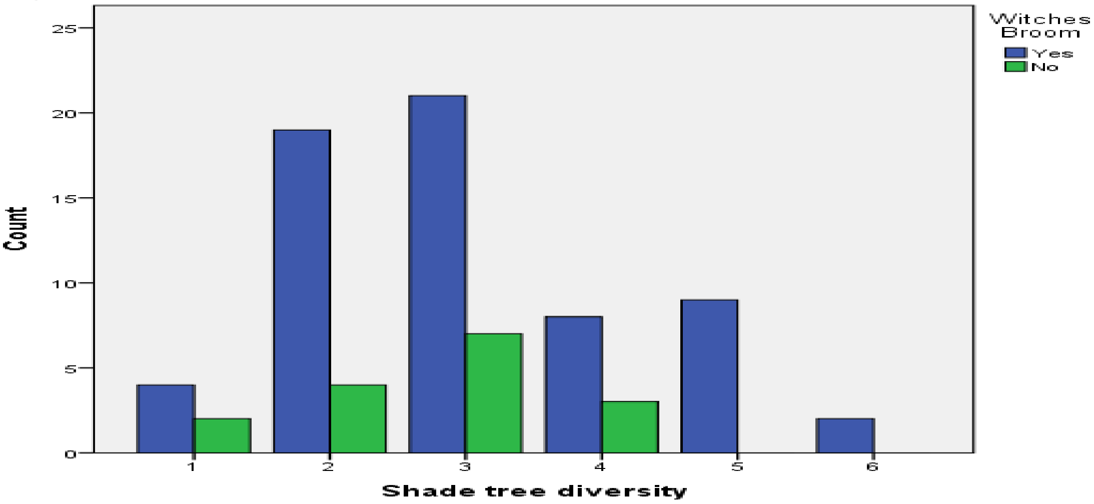
Figure 3. Incidence of Witches Broom Disease.



Source: *Primary data (2021)*

Other diseases, frost pod rot, cocoa swollen virus, and dieback diseases, showed variations depending on the shade tree diversities and species, with no significant positive numbers of non-diseased cases reported. Across all shade tree diversities, more disease cases were reported than normal cases, suggesting an association between these shade trees and specific diseases, favouring their occurrence on these farms as hosts. Overall, the variation in disease occurrence was not uniform but rather scattered, indicating the influence of shade trees on disease prevalence across farms.

Pruning as a farming practice was identified as one of the key strategies in addressing the prevailing diseases on cocoa farms. Most farmers associated this practice with disease control. Besides, clearing gardens and weeding were other practices identified to control pests and diseases in cocoa farms. Farmers are also highlighted on the selective cutting of infected pods, manually killing insects, ensuring proper fermentation, removing coupons after clearing, and practising proper bean drying. These management strategies were found crucial for controlling pests and diseases in cocoa farms within Bundibugyo District.

Table 3 Summary for the Analysis of the Influence of Shade Tree Diversity on Disease Incidence

Shade Diversity		Disease Prevalence														
		Black pod rot			Witches Broom			Frosty pod rot			Cocoa swollen			Dieback disease		
		Y	No	Tot	Y	No	Tot	Y	No	Tot	Y	No	Tot	Y	No	Tot
	Yes	6	0	6	3	5	8	6	1	7	6	4	10	6	1	7
1	Total	6			8			7			10			7		
	Yes	23	0	23	14	13	27	21	3	24	21	5	26	22	4	26
2	Total	23			27			24			26			26		
	Yes	28	0	28	15	20	35	28	5	33	27	11	38	29	8	37
3	Total	28			35			33			38			37		
	Yes	12	0	0	6	8	14	12	0	12	7	8	15	13	3	16
4	Total	12			14			12			15			16		
	Yes	9	0	9	9	0	9	9	0	9	6	9	15	8	0	8
5	Total	9			9			9			15			8		
	Yes	2	0	2	2	0	2	2	0	2	2	0	2	2	0	2
6	Total	2			2			2			2			2		

1 Tree species, 2 Tree species, 3 Tree species, 4 Tree species,5 Tree species, 6 Tree species

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DISCUSSIONS

There were three major areas against which this discussion centered; the influence of shade tree diversity on disease incidence. Five cocoa diseases and six shade tree diversities. Cocoa diversity systems attracted special attention due to their economic, social, and ecological significance, Olwig *et al*. (2023), acknowledge the presence of diseases in cocoa plantations. The association between diseases and the presence of shade diversity varied depending on the type of disease, as indicated in the results. The pattern of association was not consistent across all diseases and could have been influenced by various factors including soil fertility, biodiversity, age of cocoa plantation, shade characteristics, and cocoa density (Wessel, & Quist-Wessel, 2015; Nkamleu, & Kielland, 2006).

Agroforestry, defined as a land-use management system combining agricultural and forestry technologies, aims to create diverse, productive, profitable, healthy, and sustainable land-use systems (Sudomo *et al*., 2023). Shaded cocoa plantations facilitate the dispersal of forest fauna between fragments. The biodiversity of plants and animals found within shaded cocoa systems can enhance ecosystem services such as pest control, pollination, weed control, fungal disease limitation, and soil fertility, (Sudomo *et al*., 2023), agrees with this study about ecosystem complements on a given farm unit.

The association between pod rot disease and the presence of shade diversity was not significant, with disease incidence reported on farms regardless of the type of shade diversity present. On the other hand, the association between witch's broom disease incidence and the presence of shade tree diversity was significant. This could be attributed to the age of the cocoa plantations, as most were over 10 years old (Etaware, 2022). Older cocoa plantations were found to have a negative significant effect on witches' broom disease control, with lower incidence associated with younger cocoa plantations. This finding aligns with the results of (*Ecosystem Services in Fine Flavor Cocoa Agroforestry Systems from Ecuador*, 2019), which observed a similar effect of cocoa age on witches' broom disease incidence during a 14-year trial in Brazil. They argued that older and larger trees favour the production and dissemination of witches' broom inoculum due to their increased meristematic fluid. This research corroborates these findings, as most farms surveyed were over 14 years old.

Associations between black pod, frost, swollen shoot, cocoa dieback, and the presence of shade diversity were not significant, with no clear pattern of disease occurrence observed on the selected farms for this research Table 2. Etaware (2022), noted that cocoa swollen virus and *Phytophthora* pod rot are common cocoa diseases that could be influenced by various factors. Further studies are warranted to identify the specific causes of such diseases within cocoa plantations and to identify specific shade tree species of economic importance. Shinyekwa et al., 2017 highlighted that the occurrence of trees on cocoa farms is primarily due to natural regeneration, limiting farmers' control over tree species selection. This practice allows for cost-effective tree establishment but restricts tree diversification options.

The effect of shade tree species on disease incidence; the association between black pod rot disease and the presence of all tree species was non-significant. The disease incidence was not influenced by the presence of the tree species. The association between witch’s broom, swollen shoot virus, dieback, frosty pod rot and the presence of *Maesopsis eminii* was highly significant.

Maesopsis eminii is likely to be a host for cocoa diseases and farmers need to be careful planting it as a shade tree. (*Ecosystem Services in Fine Flavor Cocoa Agroforestry Systems from Ecuador*, 2019) says cocoa swollen virus and *phytophthera* pod rot are common diseases of cocoa. Trees are applied to crops for purposes of shade environment, reduce costs of weeding, control disease attacks and increase the quality and taste of cocoa but should be selected trees (Sudomo et al., 2023).

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In other studies, some trees have been kept on the farm for multipurpose uses in the form of timber, fodder, fruit trees and biodiversity services. (Foroughbakhch et al., 2010) agree with this study about the use of multipurpose trees on plantations. A summary of disease incidences with different tree species on selected cocoa farms is indicated in Table 2.

There was a non-significant association between diseases under this study with the presence of these tree species, (Jackfruit) *Artocarpus heterophyllus,* (African white wood) *Triplochiton seleroxylon,* (white nongo) *Albizia glaberrima,* (Gliricidia) *Gliricidia sepium, (Foothill pine) Pinus sabiniana,* (palm tree) *Arecaceae,* (Broom cluster) *Ficus capensis,* (Guava tree) *Psidium guajava*, (African tulip tree) *Spathodea campanulate,* (Beach mulberry) *Morinda* and farmers need to be encouraged to plant such trees for shade and agro-ecological purposes. Hernández-nuñez (2024), says practical agroecology is seen as a systemic and holistic approach for the farm's ecosystems. Core techniques and practices include: minimizing and ideally omitting chemical nutrients and high energy use; making use of the properties of the whole farming systems like recycling nutrients, building the soil organic matter and preserving Agro-biodiversity and resources.

Prevalence of cocoa diseases under different agroforestry systems; According to the results, all of the respondents asserted that pests affect their Cocoa farm and these were 82 (100%). Regarding the pests affecting the cocoa farm production, 79 (96%) asserted that their farms were attacked by Cocoa pod borer, followed by Mealy bugs 65 (79%) and the least represented pest was Thrips 46 (56%). The study also established that the majority of the respondents asserted that diseases affect their Cocoa farms and these were 81 (99%), these respondents also asserted that Black pod disease was the most dominant disease represented in over 80 farms (98%), followed by Frosty pod rot 69 (84%) and the least represented disease affecting cocoa farm production was Cocoa swollen shoot virus represented in over 44(54%) (Vanoverschelde, 2023).

The study further established in the results presented that the highest frequency of cocoa diseases attacking the farm was in the Rainy Season as asserted by 59 (72%) followed by the dry season represented in only 21 farms (26%). The highest impact of pest and diseases attack on cocoa farms in Bundibugyo district was the deteriorating Quality of products as reported by 75 farmers (92%), followed by the poor health of the crop as asserted by 44 farmers (54%) and the least represented impact of pest and diseases attack on cocoa farms is the deteriorating livelihood of the farmer in Bundibugyo district as reported by 33 farmers representing 40.2%.

The study also established that the problems faced in ensuring quality cocoa beans in Bundibugyo are vast, however, Pests and Diseases were the most dominant problem as reported by 68 farmers (83%), followed by the problem of Erratic rainfall reported by 64 farmers (78%), followed by the problem of the Long distance of cocoa farms reported by 54 (66%) and the least reported problem was High cost of spraying as asserted by only 10 (12%).

CONCLUSION AND RECOMMENDATIONS

Conclusion

Cocoa diseases had a more significant impact on the shade diversities (2-3 tree species), followed by the shade diversities (1-2 tree species). Furthermore, the study concluded that Black pod disease was the most significant disease affecting cocoa farms under different agroforestry systems in Bundibugyo district.

However, the research also noted the presence of other cocoa farm diseases such as Frosty pod rot, cocoa dieback, witches broom, and cocoa swollen shoot virus. Therefore, cocoa farmers in Bundibugyo district should prioritize the management of black pod disease, considering its significant impact on cocoa farms.

It was discovered that cocoa farm pests and diseases had a more substantial impact during the rainy season compared to the dry season. Additionally, these pests and diseases mainly

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affected the quality of produce from cocoa farms in the Bughendera constituency, Bwambale et al., (2021) highlighted the same challenge of cocoa disease during his research on cocoa diseases. The study also identified other negative impacts, including the poor health of crops, deteriorating prices of cocoa farm products, reduced quantity available for market, and adverse effects on the livelihoods of farmers.

Recommendations

Farmers in the Bundibugyo district should focus on adopting other management strategies which have been scientifically approved to address the prevalence of cocoa diseases under different shade diversities.

Farmers are also advised to carefully examine the type of shade trees planted on their farms since different tree species have different associations with cocoa diseases.

Pests and diseases pose a significant problem for cocoa farmers, with all cocoa farmers in the study area reporting their farms being affected. Specifically, the Cocoa pod borer and Black pod disease should be given utmost attention due to their prevalence in most farms in Bundibugyo district.

Farmers are encouraged to be more vigilant during the rainy season, as this is when the highest frequency of cocoa diseases and pests occurs in cocoa farms.

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Statement of Conflict of Interest:

On behalf of the team of authors and on my behalf, I certify and declare no conflict of interest in this paper. All processes were conducted professionally in a manner that upholds high integrity. All work has been produced in its original form.

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