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Agroforestry as Climate Change Adaptation

The Case of Cocoa Farming in Ghana

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CHAPTER 3

Shade Tree Species Matter: Sustainable Cocoa-Agroforestry Management

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Abstract Shade trees are important components of cocoa-agroforestry systems because they influence yields, soil fertility and the occurrence of pests and diseases and may support adaptation to climate change. Based on a review of the existing literature and on primary data from field experiments, this chapter reports on the species-specific effects of shade trees in relation to the management of insect pests, black pod diseases and their impacts on cocoa yield. Shade tree species in cocoa

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systems impact soil available phosphorus differently and shade tree species such as Spanish cedar (*Cedrela odorata*), limba (*Terminalia superba*) and mahogany (*Khaya ivorensis*) increase cocoa yield compared with cocoa systems without shade trees. The architecture of shade tree species may influence below-canopy temperatures and relative humidity, which potentially affect pests such as mirids and black pod disease infections and ultimately cocoa yield. As farmers have local knowledge of and preferences for certain shade tree species, strengthening the combination of scientific and local knowledge can prove a powerful tool for the improved management of shade tree species, as well as cocoa pests and diseases.

Keywords Pests and diseases · Black pod disease · Mirid · Soil fertility · Yield · Climate change

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3.1 Introduction

In the tropical regions where cocoa (*Theobroma cacao* L.) is cultivated, many different factors may result in low yield and reduced revenues from the production of the world's raw material for chocolate. These include poor farming practices, the occurrence of pests and diseases and worsening weather conditions due to climate change. Cocoa farmers and cocoa-producing countries must identify strategies that support sustainable production. In addition to improving yield through the development of high-yielding and disease-resistant cocoa varieties (Edwin & Masters, 2005; Mcelroy et al., 2018) and improving fertilizer regimes (Hoffmann et al., 2020; Niether et al., 2019), agroforestry has been recognized as an important means to improve cocoa yield (Asitoakor et al., 2022a). Agroforestry, the deliberate cultivation of crops with forest or food trees, is generally more environmentally friendly than monocropping systems and serves as an important climate change adaptation measure, especially for Sub-Saharan Africa, where most of the global cocoa production takes place (Vaast et al., 2016).

Sustaining cocoa yield is a major challenge for smallholder farmers, especially under worsening climatic conditions with reduced rainfall and increasing temperatures (see Chapter 1). Smallholder farmers lack the capacity to irrigate and afford the required inputs, labour and other agronomic support needed to achieve high yield. Currently, rainfall is erratic in most of the West African cocoa region and below the optimal ranges of 1,500–3,000 mm for cocoa production (Abdulai et al., 2020; IITA, 2009). Temperatures in these areas are increasing (Ruf, 2011; Tscharntke et al., 2011) above the optimal annual maximum of 30–32 °C. Under high temperature and low rainfall conditions, cocoa phenology and performance with regard to flowering and fruiting are impeded (Adjaloo et al., 2012; Asitoakor et al., 2022b; Daymond & Hadley, 2008; Medina & Laliberte, 2017, see also Chapter 2) and insect infestations and the proportions of small size (low-grade) and defective beans increase (Asante-Poku & Angelucci, 2013). In major cocoa areas in Ghana and Côte d'Ivoire, low yield due to pests and diseases, high input demands and the high cost and low availability of labour leave farmers with the question of whether or not to replant their cocoa plots with other crops such as oil palm (*Elaeis guineensis*) and rubber (*Hevea brasiliensis*) (Cocoa Barometer, 2022; Ruf, 2015) or shift to other forms of land use (see Chapter 4). However, the adoption of agroforestry with selected beneficial shade trees might prove cost-effective, preserve the environment and sustain yield (Asare, 2016; Babin et al., 2010; Ofori-Frimpong et al., 2007; Tscharntke et al., 2011; van Vliet et al., 2015, see also Chapter 5).

The scientific debate on the role of agroforestry in cocoa production has been going on for decades, with many arguing that the advantages of shade trees in cocoa systems outweigh their disadvantages, particularly when tree species that are adapted to the local social and agroecological contexts are adequately managed. Benefits from shade trees include carbon sequestration, biodiversity conservation, alternative income for farmers, soil improvement, prevention of erosion and the management of micro-climatic conditions that, among other things, reduce pest and disease infestations (Abdulai et al., 2018; Niether et al., 2019; Tscharntke et al., 2011). However, some tree species serve as alternative hosts for pests (e.g. mirids) and diseases in cocoa systems (Mahob et al., 2015) and they may also compete for nutrients, water and sunlight (van Vliet & Giller, 2017). Common species of shade trees in West Africa include fruit trees such as avocado (*Persea americana*), orange (*Citrus sinensis*), coconut (*Cocos nucifera*) and mango (*Mangifera indica*), as well as timber-producing species such as mahogany (*K. ivorensis*), ceiba (*Ceiba pentandra*) and teak (*Tectona grandis*) (Rigal et al., 2022).

Shade trees are important sources of food and local pharmaceutical raw materials for curing diverse illnesses and diseases (Rao et al., 2004). For example, cola nuts (*Cola nitida*) provide an important ingredient in beverages such as Coca Cola and Pepsi Cola, and are used for short-term relief from fatigue, depression, chronic fatigue syndrome (CFS) and melancholy (Atolani et al., 2019). Flat-crown tree (*Albizia adianthifolia*) is another important shade tree also used for treating diabetes, headaches, eye problems, wounds, pain, skin diseases, gastrointestinal problems, haemorrhoids, infertility in women, respiratory problems and sexually transmitted diseases (Lemmens, 2007a). The bark decoction of mahogany (*K. ivorensis*) is used in the treatment of coughs, fever, malaria, anaemia, wounds, sores, ulcers, tumours, rheumatic pains and lumbago (Lemmens, 2008). Aside from the medicinal role of common shade tree species, the wood from species like stoolwood (*Alstonia boonei*), Spanish cedar (*C. odorata*), African teak (*Milicia excelsa*) and black afara (*Terminalia ivorensis*) are used for construction and furniture, including the building of canoes, roofing and household items such as stools, boxes, tables and chairs (Adotey et al., 2012; Foli, 2009; Lemmens, 2008; Ofori, 2007).

Farmers have clear ideas about the tree species they prefer and the types of shade trees that may provide different types of ecosystem services (Rigal et al., 2022). Farmers' reasons for selecting specific shade tree species include their influence on cocoa yield, their income-generating potential, their medicinal properties, their use in construction and whether they serve as sources of fuelwood (Appendix). Nonetheless, the ecological interactions between shade tree species, pests and diseases and their influence on cocoa yield are poorly known. Few studies have documented the varied impacts of different shade tree species on cocoa production (Abdulai et al., 2018; Asare et al., 2019; Graefe et al., 2017). Asare et al. (2019), in an on-farm study conducted in the Ashanti and Western regions of Ghana to understand the relationship between the canopy cover of shade trees and fertilizer regimes on yield, observed a doubling of yield, as shade cover increased from zero to 30% in 86 plots. The study further showed fertilizer application to have increased yield by 7%. In a study by Kaba et al. (2020), African tulip tree (*Spathodea campanulata*), limba (*T. superba*) and black afara (*T. ivorensis*) were the most desirable tree species, while stoolwood (*A. boonei*) was the least desired in cocoa systems in Ghana's semi-deciduous rainforest zone from the farmers' perspective. The different species' desirability was linked to their influence on cocoa and other food crops around shade trees, the suitability of shade trees as fodder and the general improvement in pod and cocoa-tree health. Graefe et al. (2017) identified *T. ivorensis*, *T. superba*, *M. excelsa*, *A. boonei* and *Pycnanthus angolensis* (African nutmeg) as the five most desired shade tree species by cocoa farmers across Ghana's cocoa belt. The five species were preferred to other species for their compatibility with cocoa, as they were perceived to provide the right amount of shade, improve soil moisture and fertility, have a fast rate of leaf decomposition and suppress weeds. Shade species such as the African corkwood tree (*Musanga cecropioides*), Ceiba (*C. pentandra*), Akee apple tree (*Blighia sapida*), African crabwood (*Carapa procera*) and giant cola (*Cola gigantea*) were assessed by farmers to be less desirable due to their heavy shade, below-ground competition, slow leaf decomposition, being an alternative host for pests and diseases, and causing physical damage to cocoa. Abdulai et al. (2018) observed the common use of gliricidia (*Gliricidia sepium*), avocado (*P. americana*), orange (*C. sinensis*) and the boundary tree (*Newbouldia laevis*) in the mid- and wet cocoa regions in Ghana. According to the authors, G. *sepium* was considered important for soil improvement, *P. americana* and *C. sinensis* for food and *N. laevis* for use as live stakes for yam (*Dioscorea* sp.). In our study, as will be discussed further below, *C. odorata*, *T. superba* and *K. ivorensis* are identified as good shade tree species, associated with more than 40% higher yield of cocoa compared with unshaded cocoa systems (Asitoakor, 2021). Conversely, species like *A. boonei* are viewed differently from place to place, perhaps depending on the specific needs and uses of the species, aside from shade provision.

In many instances, the relationship between shade trees and cocoa yields is attributed to the variations in shade tree structure and growth rates that affect their interactions with cocoa trees (Asante et al., 2021; Asitoakor et al., 2022a). However, there is a need for more knowledge concerning the properties of shade tree species to improve shade tree selection in cocoa-agroforestry systems. This chapter draws on the existing literature and the results of a three-year on-farm experimental study focusing on how eight different agroforestry shade tree species influenced soil nutrients, mirids (*Sahlbergella singularis* Hagl. and *Distantiella theobroma* Dist.) and black pod diseases (caused by *Phythophthora palmivora*, and *P. megakarya*) infections. The next section, Sect. 3.2, highlights the influences of the selected shade tree species on soil fertility and yields in cocoa systems, while Sect. 3.3 shows how the selected shade tree species affected cocoa pests and disease infestations.

3.2 Role of Shade Trees in Soil Fertility and Yield in Cocoa-Agroforestry Systems

Soil fertility may be defined as the capacity of the soil to support the growth and yield of plants (Young, 1990). As with other crops, cocoa yield is directly related to soil fertility, age of the cocoa plant, prevailing climatic conditions (in terms of rainfall, temperature and relative humidity) and agronomic practices (Asante et al., 2021; Asitoakor et al., 2022a). In addition to these factors, the type of shade tree species intercropped on cocoa farms influence the performance of the cocoa plants (Asitoakor et al., 2022a). Though the fertility of cocoa soils varies by location, landscape and number of years under cultivation, the maintenance of soil pH and the availability of organic carbon, nitrogen, phosphorus, potassium, calcium and magnesium in the soil may be influenced by shade tree interactions. For example, leguminous shade trees may play a positive role in fixing nitrogen (N), and hence the availability of nitrogen for the cocoa plants. Shade trees also contribute to nutrient recycling through litter decomposition (Asigbaase et al., 2021) and play a role in preventing soil erosion and regulating atmospheric temperatures that are directly linked to soil temperatures, moisture and cocoa root-associated microbiome and activities (Schmidt et al., 2022). Furthermore, shade trees provide habitats for fauna (birds, insects, etc.) that are essential in cocoa pollination and in the provision of other essential ecosystem services that benefit cocoa plants. However, the role of shade trees in cocoa systems depends on their general structural architecture above ground and whether the root systems overlap with the desired crops (cocoa) (Asante et al., 2021; Rigal et al., 2022).

Higher cocoa yield was reported under no-shade conditions compared to shaded conditions in a pioneering long-term study of the relation between shade and cocoa nutrition (Ahenkorah et al., 1987). This study was conducted with high inputs of fertilizer and other agrochemicals. These findings contrasted with our findings from the Western region of Ghana, where we observed more than 40% higher yield in shaded plots compared to unshaded plots (Asitoakor et al., 2022a). A main difference between the two studies, which may have led to the contrasting results, was that in our study agricultural inputs were relatively low, reflecting the input use of the majority of Ghanaian farmers. Our study also suggested modest impacts of shade trees on nutrient availability, as we observed no significant differences between shaded and unshaded plots in terms of soil concentrations of total nitrogen, exchangeable potassium, calcium and magnesium. Nonetheless, we found differences in the potentials of eight common forest shade tree species with regard to the concentration of available phosphorus (P) in comparison with the unshaded control plots (Fig. 3.1(a)) (Asitoakor et al., 2022a). The unshaded control plots in Fig. 3.1(a) showed the highest concentration of available P compared with plots with shade trees. The possibility that the shade trees may have competed with the cocoa plants and absorbed some of the soil P has been raised as a concern by some researchers (Gateau, 2018). Although there is less available soil P below shade tree species than in the control plots, this was not the limiting factor, as cocoa yield under these tree species were higher than in the unshaded control plots (Fig. 3.1(b)). This was expected, as Isaac et al. (2007) and Asare et al. (2017) have documented the possibility of improving yield from enhanced nutrient uptake by cocoa trees under shade trees when water is not a limiting factor.

Traditionally, cocoa farmers have sustained cocoa production through expansion into forest areas and/or by intensification through the addition of fertilizers (organic and/or inorganic) and through the chemical control of pests and diseases in varying quantities based on their affordability

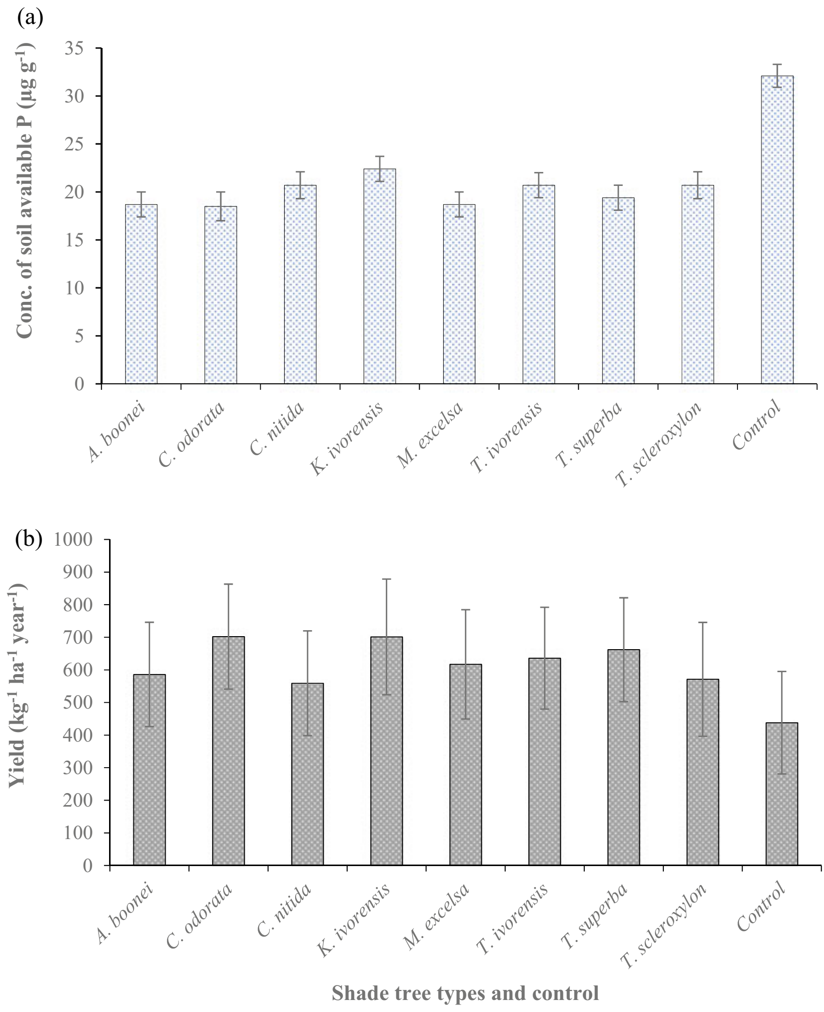

Fig. 3.1 The relationship between the selected shade tree species and unshaded control and **(a)** soil available phosphorus, and **(b)** cocoa yield in the three-year (2018–2021) field study (Values represent mean ± s.e. Creative Commons Attribution BY 4.0)

and availability. While expansion into forests results in forest degradation and loss of biodiversity, the irrational application of agro-chemical inputs could lead to soil degradation and other environmental problems such as water pollution, habitat destruction and biodiversity loss including beneficial pollinators (Adu-Acheampong et al., 2015; Bhandari, 2014). Although application of the right fertilizers increases yield (Asare et al., 2019), it could have negative influences on the composition of the root-associated microbiome of cocoa if the right amounts are not applied at the recommended rates, thereby reducing the decomposition of organic matter and the natural nutrient-recycling potential of cocoa soils (Niether et al., 2019; Schmidt et al., 2022). Likewise, the application of ammonium-based fertilizers can increase the acidity of cocoa soils and may reduce the potential of the soil to support yield after prolonged usage. Although organic fertilizers are considered better than inorganic fertilizers from an environmental safety perspective, few farmers use them. Since both organic and inorganic fertilizers are costly, planting and managing shade tree species that are known to improve soil fertility may be an economic alternative. There is a need for better management practices and policy incentives that reduce production costs, protect the environment and sustain yield.

Many studies have evaluated cocoa yield under both shaded and unshaded (full-sun) systems (Abdulai et al., 2018; Ahenkorah et al., 1987; Asare et al., 2017), but species-specific studies are rare. In our field study involving eight forest shade tree species, species such as *C. odorata*, *T. superba* and *K. ivorensis* resulted in significantly higher cocoa yield than full-sun control plots (Fig. 3.1(b)) (Asitoakor et al., 2022a). As mentioned above, the recorded yield did not correlate with nutrient availability (such as P) expressed by the control plots in Fig. 3.1(a). This showed that the productivity of cocoa is influenced by other factors than just soil fertility. This may include the architecture of the shade trees above the cocoa trees. The tree species with the highest yield, *C. odorata*, *T. superba* and *K. ivorensis*, all have tall stems and less dense canopies compared to species, such as *C. nitida*, which have relatively short stems and dense canopies. However, since there were no significant differences between species, further studies are needed before a definite conclusion can be made on this aspect. Asante et al. (2021) suggested that the architecture of shade trees is critical for levels of aeration, light penetration and the nutrient-recycling potential in cocoa-agroforestry systems. Interestingly, the average yield recorded in Fig. 3.1(b) in the plots under shade trees was higher than the unshaded control plots, as well as the national average cocoa yield between 400 and 550 kg ha^{-1} across Ghana, Côte d'Ivoire, Nigeria, Cameroon and Togo (Bymolt et al., 2018; Oomes et al., 2016).

3.3 Shade Tree Influences on Cocoa On-Farm Pests and Diseases

Pests and diseases in cocoa are managed mainly by pesticide and fungicide applications. Mirids (*S. singularis* Hagl. and *D. theobroma* Dist.) and black pod diseases (caused by *P. palmivora* and *P. megakarya*) are the major cocoa pests and diseases in West Africa (Adu-Acheampong et al., 2015; Akrofi et al., 2015). Due to the environmental and health risks associated with the application of pesticides, coupled with the high costs involved, integrated pest management (IPM) approaches have been recommended to control pests and diseases in cocoa (Adu-Acheampong et al., 2015; Dormon et al., 2007). Integrated pest management relies on close monitoring and knowledge of the pests and pathogens and involves combining natural or biological pest control mechanisms (Bajwa & Kogan, 2002; Kabir & Rainis, 2015). As in other agricultural systems, the micro-climatic conditions (temperature, rainfall and relative humidity) strongly influence pest and disease occurrence and impact (De Almeida & Valle, 2007). For example, low temperatures and high relative humidity under shade trees favour black pod disease (Fig. 3.2(a)), while high temperatures under low rainfall conditions tend to favour some insects (e.g. mirid in Fig. 3.2(b)) (Abdulai et al., 2020; Dormon et al., 2007). In Africa, mirids are widespread in the major cocoa areas and cause up to 75% yield losses when uncontrolled (Anikwe et al., 2009; Padi, 1997). Black pod disease predominates on West African cocoa fields, resulting in up to 80% losses in cocoa yield (Akrofi et al., 2015). High relative humidity from high rainfall and poor drainage conditions in cocoa systems promote fungal black pod disease, which peaks in May–June on most cocoa farms in West Africa (Akrofi et al., 2015; Opoku et al., 2000). These occurrences may be minimized or regulated through the adoption and good management of agroforestry practices, including regular pruning and the removal of mistletoe and diseased pods to sustain cocoa yield.

In Ghana, governmental and non-governmental agencies organize farmer training, support extension services and provide support with pesticides, spraying and pruning programmes, all to reduce mirid infections and black pod disease (Baah & Anchirinah, 2011; Cocoa Health and Extension Division [CHED] & World Cocoa Foundation [WCF], 2016). Such efforts have been ongoing for decades (Adu-Acheampong et al.,

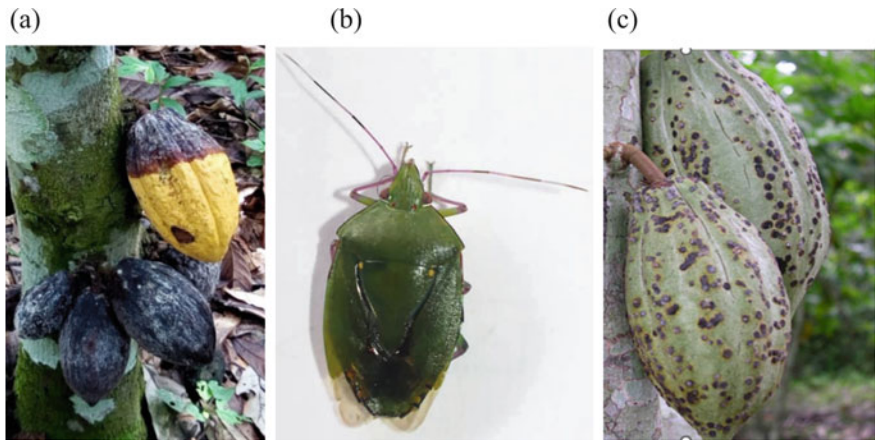

Fig. 3.2 Important biotic stressors in cocoa. **(a)** Pods infected by black pod disease (caused by *Phythophthora* sp.), **(b)** mirid insect (*Sahlbergella singularis*) and **(c)** damage symptoms of mirid infection on cocoa pods (*Source* **(a)** and **(c)**: Asitoakor (2021); **(b)**: Photo by Bawa Abuu)

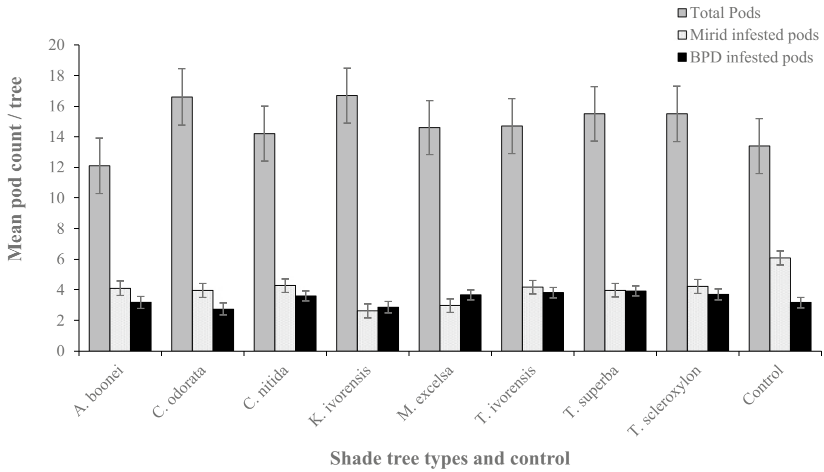

Fig. 3.3 Mean distribution of mirid insects and black pod disease infestations in cocoa pods under eight selected shade trees and in unshaded control areas (Values indicate mean ± s.e. Creative Commons Attribution BY 4.0)

2015; Akrofi et al., 2015). Since the 1950s, the development of resistant cocoa varieties and improved pesticide applications have been the major approaches to resolving the challenges of mirids and black pod diseases (Adu-Acheampong et al., 2015). However, the high costs of approved chemicals make farmers resort to using cheaper and unapproved pesticides that may reduce yield and risk contaminating the cocoa beans (Adu-Acheampong et al., 2015). With recent increases in global demand for cocoa beans free from agro-chemical residues (Cocoa Barometer, 2022), more biological ways of controlling pests and diseases in cocoa production have become desirable. Adu-Acheampong et al. (2015), however, question the existence of viable natural approaches to the management of cocoa pests and diseases. In our recent study of mirid insects and black pod disease infestation and damages in cocoa-agroforestry systems in Ghana, we observed variations in the magnitude of infection among eight selected shade trees species, as shown in Fig. 3.3 (Asitoakor et al., 2022a). The study confirmed that the level of mirid damage on cocoa pods may be effectively managed by the right combination of shade tree species and cocoa. Likewise, although black pod disease infections seem to be higher under shade trees than in unshaded plots, there could also be species-specific responses in that respect. The authors recommended further research to unravel species-specific responses to black pod infection in cocoa.

3.4 Conclusion and Policy Implications

In Ghana, shade trees are important components of cocoa-agroforestry systems, because they influence the occurrence and management of pests (mirids) and diseases (black pod disease) and improve yield in comparison to unshaded conditions. Shade trees have varying architecture, leaf sizes and crown densities that influence microclimate differently, thus impacting the occurrences of mirids and black pod diseases. Species such as Spanish cedar (*C. odorata*), limba (*T. superba*) and mahogany (*K. ivorensis*), which have less dense canopies, increase yield when used as shade trees in cocoa-agroforestry systems. Other species may have similar functions, but more research is required to understand how different shade tree species affect cocoa trees. Cocoa farmers are knowledgeable and have their preferred shade trees, and there is a need to combine local knowledge with scientific knowledge to guide the selection of shade tree species in cocoa-agroforestry systems to increase yield and mitigate climate change.

Current cocoa-related policies in Ghana promote the adoption of shade trees on cocoa farms with limited and unclear directions for selecting the specific types of shade trees. Unsuitable combinations of shade trees and cocoa may lead to increases in pest and disease incidence and severity, and negatively affect cocoa yield and quality. To ensure that the integration of shade trees does not harm cocoa production, and to increase farmers' interest in and satisfaction with keeping shade trees on their cocoa farms, policy development and dissemination by all relevant stakeholders in the cocoa sector is necessary. This includes the agricultural and cocoa-governing bodies such as the Ministry of Food and Agriculture of Ghana (MoFA) and the Ghana Cocoa Board (COCOBOD). Also private actors such as cocoa-based non-governmental organizations, farmer associations and cocoa-buying companies should critically consider the type of shade trees they recommend to cocoa farmers. Our study provides some insights on shade trees and the management of pests and diseases, but more knowledge is needed regarding the services and disservices of shade trees in cocoa cultivation.

Appendix: List of Common Shade Tree Species Adopted in Cocoa-Agroforestry Systems and Their Additional Uses

No	*Scientific name*	*Common uses*	*Reference*
1	*Albizia adianthifolia*	Treating diabetes, headache, eye problems, wounds, pain, skin diseases, gastrointestinal problems, haemorrhoids, infertility in women, respiratory problems and sexually transmitted infections	Lemmens (2007a)
2	*Albizia ferruginea*	Construction, flooring, staircases, furniture, cabinetry, joinery, turnery, carvings and veneer	Twum-Ampofo (2007)
3	*Albizia glaberrima*	Construction and furniture, stools, beehives, tool handles and grain mortars	Lemmens (2007b)
4	*Albizia zygia*	Carving, flooring and furniture. Bark decoction: treating bronchial diseases, fever, malaria, female sterility and as a purgative, stomachic, antidote, vermifuge and aphrodisiac	Apetorgbor (2007)
5	*Alstonia boonei*[a]	Boats, furniture, sculptures, musical instruments and firewood. Bark decoction: treating fractures and dislocations, jaundice and inducing breast milk	Adotey et al. (2012)
6	*Amphimas pterocarpoides*	Wood: interior construction, flooring, interior trim, joinery, furniture, canoes, huts. Bark decoction: treating dysentery, anaemia, haematuria, dysmenorrhoea, blennorrhoea, schistosomiasis, mumps and as a poison antidote	Tchinda and Tané (2008)

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(continued)

No	*Scientific name*	*Common uses*	*Reference*
7	*Anthocleista sp.*	Treating diabetes, hypertension, malaria, typhoid fever, obesity, diarrhoea, dysentery, abdominal and chest pain, ulcers, jaundice, asthma, haemorrhoids, hernia, cancer, rheumatism, STDs, infertility and skin diseases	Anyanwu et al. (2015)
8	*Antiaris toxicaria*	Sap: as an agent for immobilizing animals during hunting	Bosu and Krampah (2005b)
9	*Antrocaryon micraster*	Bark: preparing soup, treatment of malaria and as an enema to treat impotence and threatened abortion	Ayarkwa (2011)
10	*Blighia sapida*	Food and cosmetics production. Also for treating backache, constipation, cancer, fever, gonorrhoea, dysentery, psychosis, hernia, stomach-ache, malaria, rheumatism, typhoid, etc.	Sinmisola et al. (2019) and Asamoah et al. (2010)
11	*Bombax buonopozense*	Bark, flowers and leaves: treating ringworm, swellings, fever, convulsions and insanity and to clean hairy leather	Danso et al. (2019)
12	*Cedrela odorata*[a]	Cigar boxes, construction, joinery, mouldings, panelling, louvred doors, boats, furniture, cabinetry, household implements, musical instruments, carvings, veneer, plywood and turnery. Root and trunk bark: treating fever and pain	Lemmens (2008)
13	*Ceiba pentandra*	Construction. Its fluffy cotton-like seed pods are used as stuffing materials for cushions, pillows, mattresses, insulation and absorbent	Duvall (2011)
14	*Celtis mildbraedii*	Construction, furniture and ladders. Also for poles, pestles, tool handles and spoons	Oyen (2012)

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No	*Scientific name*	*Common uses*	*Reference*
15	*Celtis zenkeri*	Construction, flooring and fuelwood	Essien and Oteng-Amoako (2012)
16	*Citrus sinensis*	Food and for producing beverages. The peel: increase appetite, reduce phlegm and treat coughs, colds, intestinal gas (flatulence) and acid indigestion	Yerou et al. (2017)
17	*Cola gigantea*	Treating sores, skin infections and pains	Atolani et al. (2019)
18	*Cola nitida*[a]	Producing beverages e.g. Coca Cola and Pepsi Cola. Nuts: the short-term relief of fatigue, depression, chronic fatigue syndrome (CFS) and melancholy	Atolani et al. (2019)
19	*Daniellia ogea*	Construction, flooring, joinery, furniture, novelties, boxes, crates, agricultural implements	Schmelzer (2012)
20	*Dialium dinklagei*	Food, medicine and as a source of wood	Lemmens (2012)
21	*Discoglypremna caloneura*	Bark decoction: for cough relief and intestinal pain from food poisoning. Bark powder: treating sores	Schmelzer (2008)
22	*Distemonanthus benthamianus*	Treating diarrheal infections and as wood for construction	Owusu and Louppe (2012)
23	*Entandrophragma angolense*	Bark: treating fever, stomach pain, peptic ulcers, earache, arthritic or rheumatic pain, swellings and ophthalmia, etc.	Tchinda (2008)
24	*Entandrophragma cylindricum*	Bark: treating bronchitis, lung complaints, colds, oedema, wounds and as an anodyne	Kémeuzé (2008)
25	*Erythrina vogelli*	Wood: floats for fishing nets and brake blocks and shingles. Branches: fence posts and for the relief of pain	Lemmens (2008)

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No	*Scientific name*	*Common uses*	*Reference*
26	*Ficus capensis*	Leaf decoction: as fertility agent in men and for treating dysentery, oedema, leprosy, epilepsy, rickets, gonorrhoea, anaemia, tuberculosis and pains	Nworu et al. (2013)
27	*Ficus exasperata*	Root decoctions: treating urinary tract ailments, gonorrhoea, asthma and tuberculosis. Leaves: treating swellings, wounds and arthritic joints	Nworu et al. (2013)
28	*Ficus sur*	Ornamental use and hedges	Lumbile and Mogotsi (2008)
29	*Funtumia elastica*	Treating whooping cough, asthma, blennorrhoea, painful menstruation, fungal infections and wounds	Agyare et al. (2013)
30	*Glyphea brevis*	Treating fever, gonorrhoea, dysentery, stomach and lung troubles, parasitic infections, convulsions and constipation	Dickson et al. (2011)
31	*Gmelina arboria*	Construction, carving, musical instruments, pulp, particle board, plywood, matches and packing. Leaves: fodder and for rearing silkworms. Treating common cold, sore throat, cough and flu	Adam and Krampah (2005)
32	*Hannoa klaineana*	Treating fevers, malaria and gastrointestinal disorders	Abubakaret al. (2020)
33	*Holarrhena floribunda*	Wood: carvings, combs, spoons and handles for axes and small implements. Leaves: treating diabetes, malaria, cancer and oxidant damage dysentery, diarrhoea, fever, snakebite, infertility venereal disease	Schmelzer (2006)
34	*Iryingia gabonensis*	Wood: making utensils. Fruit: food and for weight loss, high cholesterol and diabetes	Mateus-Reguengo et al. (2019)

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No	*Scientific name*	*Common uses*	*Reference*
35	*Khaya ivorensis*[a]	Wood: dugout canoes. Bark decoctions: treating coughs, fever, malaria, anaemia, wounds, sores, ulcers, tumours, rheumatic pains and lumbago. Root pulp is applied as an enema to treat dysentery	Lemmens (2008)
36	*Klainedoxa gabonensis*	Bark: treating rheumatism, lumbago, smallpox, chickenpox, fractures, dental caries, sterility and impotence	Oteng-Amoako and Obeng (2012)
37	*Lannea welwitschii*	Wood: furniture and utensils. Fruits: food. Bark; produce dye, make rope and treat diarrhoea, haemorrhoids, sterility of women, menstrual troubles, pain after childbirth, gonorrhoea, epilepsy, oedema, palpitation, skin infections and ulcers	Ebanyenle (2009)
38	*Lonchocarpus sericeus*	Remedy for pain and inflammation and as fuelwood	Amegnona and Messanvi (2009)
39	*Mangifera indica*	Food and as a beverage. Used as a dentifrice, antiseptic, astringent, diaphoretic, stomachic, vermifuge, tonic, laxative and diuretic and to treat diarrhoea, dysentery, anaemia, asthma, bronchitis, coughs, hypertension, insomnia, rheumatism, toothache, leucorrhoea, haemorrhage and piles. It is used as animal feed, fodder and forage	Lauricella et al. (2017)
40	*Margaritaria discoidea*	Bark: a purgative and for treating stomach-ache, toothache, post-partum pains, stomach and kidney complaints and to facilitate parturition. Wood: for poles, planks and shingles in housebuilding, flooring and interior trim	Addo-Danso (2012)

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No	Scientific name	Common uses	Reference
41	*Milicia excelsa*[a]	Wood: construction, furniture, joinery, panelling, floors and boats/shipbuilding and marine carpentry, sleepers, sluice gates, framework, trucks, draining boards, outdoor and indoor joinery. Bark: treating cough, asthma, heart trouble, lumbago, spleen pain, stomach pain, abdominal pain, oedema, ascites, dysmenorrhoea, gonorrhoea, general fatigue, rheumatism, sprains and as a galactagogue, aphrodisiac, tonic and purgative, treatment of snakebites and fever	Ofori (2007)
42	*Morinda lucida*	Bark, leaves and roots: treating malaria, diabetes, hypertension, inflammation, typhoid fever, cancer, cognitive disorders, sickle cell disease, trypanosomiasis, onchocerciasis and irregular menstruation, insomnia, wounds infections and jaundice	Abbiw (1990) and Zimudzi and Cardon (2005)
43	*Morus mesozygia*	All plant parts: in decoctions, baths, massages and enemas as treatments for rheumatism, lumbago, intercostal pain, neuralgia, colic, stiffness, debility, diarrhoea and dysentery. The root: as an aphrodisiac	Toirambe Bamoninga and Ouattara (2008)

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No	*Scientific name*	*Common uses*	*Reference*
44	*Musanga cecropioides*	Stem sap: treating dysmenorrhoea and galactagogue. Root sap: treating stomach spasms, diarrhoea, gonorrhoea, pulmonary complaints, trypanosomiasis, skin diseases, otitis, rheumatism, oedema, epilepsy and to ease childbirth. Wood: interior construction. Bark: treating chest pains	Todou and Meikeu Kamdem (2011)
45	*Nesogordonia papaverifera*	Wood: exterior and interior joinery, parquetry, turnery, staircase boards, window frames, furniture, cabinets, tool handles, mallets, lorry bodies, coach/wagon work and small boats, carving, sliced veneer, plywood and firewood. Leaf decoction: dental caries relief	Oyen (2005)
46	*Newbouldia laevis*	Treating coughs, malaria, diarrhoea, elephantiasis, epilepsy and dysentery, epilepsy and convulsions in children. Bark: as enema for treating constipation and piles, septic wounds and as firewood	Dermane et al. (2020)
47	*Pentaclethra macrophylla*	Leaf, bark, seed extracts and fruit pulp: treating gonorrhoea and convulsions. Also as an analgesic, laxative, enema against dysentery and liniment against itch. As firewood and charcoal	Oboh (2007)
48	*Persea americana*	Leaves: treating dysentery, coughs, high blood pressure, liver problems and gout. Bark: treating diarrhoea, fruits for lowering blood cholesterol level, promote hair growth and to treat skin conditions. It is also used to boost sexual longing	Tcheghebe et al. (2016)

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No	*Scientific name*	*Common uses*	*Reference*
49	*Petersianthus macrocarpus*	Wood: construction, furniture, canoes, mortars, tool handles, sliced veneer and plywood, flooring, mine props, vehicle bodies, railway sleepers, sporting goods, toys, novelties, agricultural implements and draining boards. Treating pains, headaches and fever	Owusu (2012)
50	*Psidium guajava*	Treating inflammation, diabetes, hypertension, dysentery, caries, wounds, pain relief, fever, diarrhoea, rheumatism, lung diseases and ulcers	Daswani et al. (2017)
51	*Pterygota macrocarpa*	Treating sores, skin infections, stomach-ache, digestive disorders and pains. Wood: veneer, plywood, interior panelling, interior joinery, moulding, furniture and block board	Oyen (2008)
52	*Pycnanthus angolensis*	Bark: poison antidote and for treating leprosy, anaemia, infertility, gonorrhoea and malaria. Leaf extracts: for enema to treat oedema. Root extracts: treating schistosomiasis. As purgative and for cleansing milk of lactating mothers and for the treating coughs and chest pains	Mapongmetsem (2007)
53	*Ricinodendron heudelotti*	Bark: treating gonorrhoea, cough, leprosy, hernia, dysentery, elephantiasis, syphilis, yellow fever, anaemia, toothache and malaria. Wood: plywood for building and construction	Tchoundjeu and Atangana (2007)

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No	*Scientific name*	*Common uses*	*Reference*
54	*Spathodea campanulata*	Food and for treating epilepsy and convulsion, kidney disease, urethritis, also as antidote for animal poisons, inflamed skin and rashes	Bosch (2002)
55	*Spondias mombin*	Treating diarrhoea, fracture, convulsion, wounds, eye and ringworm. The fruit is used for a juice drink. Leaf decoction: treating laryngitis, tooth decay, cough, sore throat and malaria	Nworu et al. (2011)
56	*Sterculia tragacantha*	Treating boils, diarrhoea, dyspepsia, fever, gonorrhoea, snake bite, syphilis and tapeworm and managing diabetes mellitus	Owusu and Derkyi (2011)
57	*Tectona grandis*	Oil extract: treating scabies and as hair tonic. Bark: treating bronchitis. Wood: construction and poles	Louppe (2005)
58	*Terminalia ivorensis*[a]	Treating dermal diseases, for firewood and charcoal. Wood: joinery, cabinetry and furniture	Foli (2009)
59	*Terminalia superba*[a]	Bark decoctions: treating wounds, sores, haemorrhoids, diarrhoea, dysentery, malaria, vomiting, gingivitis, bronchitis, aphthae, swellings, ovarian troubles, diabetes mellitus, gastroenteritis and jaundice. Wood: furniture, table tennis boards	Kimpouni (2009)
60	*Trema orientalis*	Leaves and bark: gargling, inhalation, drink, lotion, bath or vapour baths for coughs, sore throat, asthma, bronchitis, gonorrhoea coughs, yellow fever, toothache and as an antidote to general poisoning. Wood: construction, firewood and charcoal	Orwa et al. (2009)

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No	Scientific name	Common uses	Reference
61	*Trichilia manodelpha*	Treating epilepsy, depression, pain and psychosis and inflammatory conditions rheumatism, oedema, gout. Also used as firewood and charcoal	Lemmens (2008)
62	*Trilepisium madagascariense*	Leaves are used as vegetables and other parts for treating pain and venereal diseases	Ango et al. (2012)
63	*Triplochiton scleroxylon*[a]	Its sawdust is used in raising edible fungi (Pleurotus spp). Bark: to cover the roof and walls of huts. Wood: fibreboard, fuelwood and carving	Bosu and Krampah (2005a)
64	*Zanthoxylum gilletii*	Bark of stem and roots: treating burns, rheumatism, headache, stomach-ache, toothache and pain after childbirth. Bark: against colic, fever and in managing malaria, tumours and sickle cell anaemia	Okagu et al. (2021)

Note Shade tree species were selected based on findings from Asare (2016) and Graefe et al. (2017)

[a]Species used or assessed in this study

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