Potential allelopathic effects of selected shade tree species on cocoa (Theobroma cacao)

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Abstract

Shade trees on cocoa farms have been recommended without properly understanding the potential of some shade trees to release chemicals which could be injurious to cocoa. This research sought to determine the effect of aqueous extract from selected shade trees cultivated on cocoa farms on germination and growth of cocoa seedlings. Mature leaves and roots of commonly used shade trees (*Khaya anthotheca*, *Triplochiton scleroxylon*, *Melicia excelsa* and *Terminalia superba*) were collected separately and grounded into powder. Aqueous extracts of shade trees of different concentrations (15g/lit., 30g/lit. and 45g/lit) were formulated and applied to seeds and seedlings of cocoa. The study was carried out in a greenhouse which mimic field conditions. The study revealed that germination of cocoa seeds declined with increasing concentrations of *K. anthotheca*, *M. excelsa* and *T. scleroxlon*, however, *T. superba* generally did not result in further decline in germination. Higher concentrations of *T. superba* reduced dry biomass whiles that of *T. scleroxylon* increased root length with respect to the control. Farmers ranked *T. superba* as their most preferred shade species which contradicts with the findings which preferably suggest the use of *T. scleroxylon* and *M. excelsa* as shade trees in cocoa agroforestry.

Introduction

Cocoa is of significant economic importance for both producing and consuming countries. It generates export revenues, income and employment. Cocoa is an important ingredient in the confectionery, and food and beverage industries, and, more recently, in the pharmaceutical and cosmetics industries (UNCTAD, 2016).

Historically, cocoa has been established as an understory tree which is naturally existing or intentionally planted (Klein *et al.,* 2002; Anim-Kwarpong, 2003). Cocoa has been cultivated for decades in the tropics by small and marginal farmers in the shade of main and secondary forest trees (Anim-Kwarpong, 2003). Shade is always recommended for cocoa production and usually reduced progressively as the cocoa trees mature (World Cocoa Foundation, 2016). Cocoa trees need a certain level of shade, specifically in the initial stages of growth (Conservation Alliance, 2013). This is to shield cocoa seedlings from the sun and wind to enable them flourish. Generally, 12–18 shade trees *per* hectare which results in a canopy cover of 30–40% is recommended (Asare and Anders, 2016).

Shade trees provide a range of benefits to cocoa trees, soils , ecosystems and people including (i) provision of shade for cocoa trees (Asare and Anders, 2016), (ii) conservation of native trees (Asigbaase *et al.*, 2019), (iii) provision of food and fruits for farmers (Tscharntke *et al.*, 2011), (iv) enhanced farm resilience and carbon sequestration (Asigbaase *et al.* 2021a), (v) increased soil and water quality (Tscharntke *et al.*, 2011) and (vi) nutrient recycling through litterfall (Asigbaase *et al.* 2021b). Nonetheless, research studies exploring the interactions between commonly used shade tree species and cocoa trees in relation to potential allelopathy are rare (Asare, 2005).

The planting of both shade trees and cocoa plants together on the same piece of land could potentially result in an interaction where one of these plants will moderate the growth of the associated plants in a condition known as allelopathy (Fritz *et al.,* 2007). Allelo-chemicals are relinquished through the immediate surroundings which interfere in multiple physiological processes that change certain organisms' growth dynamics (Kil & Shim, 2006). Allelochemicals influence respiration, photosynthesis, enzymatic activities, water interactions, stomach opening, rates of hormones, mineral accessibility, cell splitting, elongation, cell membranes and walls, and their structure and permeation (Reigosa *et al.,* 1999; more refs here since many effects are listed). Allelopathic substances may be influenced by biochemical physiological processes such as the stomatal opening and closure, photosynthesis, and respiration. These substances in the soil may also intrude on the uptake of nutrients (Doughari, 2015)

There are several merit and demerit relationships that have been suggested for the tree and crop constituents of agroforestry systems, and the direction and magnitude of these interactions are determined by the patterns of resource sharing (Gillsepie *et al.,* 2000). In order to accomplish sustainable agriculture, the ecological connection within a given agroecosystem must be recognized (Qasem and Foy, 2001). Therefore, to ensure the sustainability of cocoa production it is important to have a better understanding of the interaction between shade trees and cocoa. This will particularly ensure that cocoa farming becomes a more viable source of livelihoods for farmers and guarantee a sustainable global cocoa economy.

Researchers have reported on the allelopathic potential of species by examining the effect of aqueous extracts on plumule and radicle length of the species (Arif, 2015; Siyar, 2018; Hachani et al. 2019). It is surmised that if species affect the growth of associated crops at the seedling or initial stages of growth, it would ultimately affect its overall performance. Currently, *Triplochiton scleroxylon*, *Khayaanthotheca*, *Melicia excelsa* and *Terminalia superba* have been promoted in cocoa plantations as shade trees, however, their potential allelopathic effects are not well understood. Therefore, we investigated the allelopathic effects of selected shade trees on cocoa seed germination and seedling growth. Our work will provide robust data on the compatibility of shade trees with cocoa, which is critical for sustainable cocoa production. Land use systems involving trees and crops are complex because a lot of complex interactions occur between the various components (Abugre et al., 2011). These interactions, which includes allelopathy, either promote or inhibit growth and development of the components (El khatib, 1997). In order to eliminate extraneous factors and yet mimic field conditions, the research was conducted in a greenhouse facility.

Materials and Methods

Description of the Study Area

This research was carried out from March, 2019 to July, 2019 in a greenhouse of the Ministry of Food and Agriculture of Ghana (MOFA) at Fiapre near Sunyani. Fiapre -Sunyani has a tropical climate with an average annual temperature of 25.7 ° C and an annual average rainfall of 1189 mm. The rainfall pattern is bimodal, with a major rainfall between April and July, followed by a short dry spell, and the minor rainfall occurs between September and October, followed by a dry season (between November and mid-March). The study area for the greenhouse is located on Latitude 7°20'54.13"N and Longitude 2°20'35.2"W (Figure 1).

Experimental Design and Treatments

The experiment was laid using Randomized Complete Block Design with three (3) replications. Each shade tree (*Triplochiton scleroxylon*, *Khayaanthotheca*, *Melicia excelsa* and *Terminalia superba*) was tested at four levels (control, 15, 30, 45 grams) and at two level of plant parts (Leaves and Roots). Eventhough litter of leaves and roots are inseparable, it is important it is important to know the plant part which affects most. The average temperature of the greenhouse was 26.7 ° C.

Source of plants used

Leaves and roots part of *Khayaanthotheca*, *Triplochiton scleroxylon*, *Melicia excelsa* and *Terminalia superba*) were obtained from Modified ‘Taungya’ plantations located in the Sunyani Forest District.

Extraction of aqueous leaf and root solutions

Fresh mature leaves (near abscission) and roots of *Triplochiton scleroxylon*, *Khayaanthotheca*, *Melicia excelsa* and *Terminalia superba* were collected from the Asukese Forest Reserve (Latitude 7° 9' 16.2" North and Longitude 2° 29' 56.6" West) which is found in a moist semi-deciduous vegetation in the Sunyani Municipality of Bono Region. Seeds of hybrid cocoa were purchased from the Cocoa Research Institute of Ghana at Goaso.

The collected dry, mature leaves and roots of *T. scleroxylon*, *K.anthotheca*, *M. excelsa* and *T. superba* were dried in an oven at 70 °C for 48 hours. The dried leaves and roots of the shade trees were ground and passed through a 40 mm mesh screen.

Using an electronic balance, 15g, 30g and 45g of the powdered leaves and roots of each tree species (*T. scleroxylon, K. anthotheca, M. excelsa* and *T. superba*) were weighed into separate and sterilized conical flasks. These concentrations were chosen based on similar studies by Maharjan *et al.* (2007) where effects were realized at these concentrations. The samples were mixed with 100 ml of purified water and stirred for 5 minutes. The mixtures were preserved for 48 hours at room temperature of 25 ºC. The aqueous extracts of the leaves and roots were then made using pressure pumps. Both solutions from leaves and roots at different concentration were kept in a dark cupboard according to the procedure used by Maharjan *et al.* (2007) and Abugre *et al.* (2011).

Germination Test

Twenty planted seeds were watered with the different aqueous plant extracts from leaves (L) and roots (R) at different concentrations (i.e. control, 15, 30, and 45 grams in 100 litres of water) of the four shade tree species. The planted seeds were watered twice a day till the seeds germinated fully. The average values (germination and growth parameters) for both leaves and roots extracts were then computed to establish the effect of the shade tree species.

Growth Performance Test

Five cocoa seedlings of five months established in poly pots were randomly selected for data collection from all the treatment concentration in each replication. Seedlings shoot length and total root length were measured and analyzed at the end of three months. Dry biomass was obtained after placing the roots and shoots in an oven at $70^{o}C$ for 48 hours. Our technique for assessing growth performance is consistent with Maharjan *et al.* (2007).

Farmer's preference for shade tree species

Factors that influence the preference of a farmer's choice of species were conducted in diverse cocoa Districts of the Brong-Ahafo Region of Ghana. Simple random sampling was employed to choose the cocoa-growing districts in the Region. After this, purposive sampling was employed to choose farmers who have benefited from the supply of shade trees species supplied by the Forestry Commission of Ghana. Questionnaires were issued to 150 farmers from the 5 districts of the cocoa production sample.

Data analysis

Data were analyzed using one-way variance (ANOVA) employing R version i386 3.6.0 software. Analysis of variance (ANOVA) was utilized to establish significant diffrences aomg the treatments. Treatment means were separated by using the Least Significant Difference (LSD) at $p = 0.05$.

Results

Effect of different extracts concentrations of *T. scleroxylon*, *K.anthotheca*, *M. excelsa,* and *T. superba* on germination of cocoa seedlings

Compared to the control, aqueous extracts of all the selected shade tree species significantly reduced cocoa seedling germination ($p < 0.05$) but the pattern of their effect on cocoa germination differed (Table 1). Whereas increased concentrations of *K.anthotheca, M. excelsa* and *T. scleroxylon* aqueous extract resulted in significant declines in cocoa seed germination ($p < 0.05$), that of *T. superba* did not differ among the aqueous extracts, even though all differed from the control (Table 1). Plant part (root verses leaves) did not have any significant effect on cocoa seed germination ($p > 0.05$) (Table 1).

Effect of different extracts concentrations of *T. scleroxylon, K. anthotheca, M. excelsa, and T. superba* on growth parameters of cocoa seedlings

Aqueous extract of *T. superba* had significant effect on shoot length and dry biomass of cocoa seedling (Table 2). Higher concentrations of *T. superba* significantly ($p < 0.05$) reduced shoot length of the cocoa seedlings. Similarly, aqueous extracts of *K. anthotheca* also resulted in reduced shoot length and dry biomass of the cocoa seedlings (Table 3). On the contrary, the different concentrations of the aqueous extracts of *T. scleroxylon* did not affect shoot length and dry biomass of cocoa seedlings (Table 4; $p > 0.05$). On the other hand, aqueous extract of *M. excelsa* influenced root length and dry biomass of cocoa seedlings (Table 5).

Generally, plant part of the various test tree species did not significantly influence shoot length, root length and dry biomass of cocoa seedlings.

Farmers' preference for shade tree species in cocoa farms

Out of the 150 farmers interviewed, the majority (67%) had shade trees growing on their cocoa farms, and (33%) were without shade trees on their farms. The majority of farmers (66%) planted different tree species on their farms with seedlings from the forestry department and (34%) were trees left on the farm during land preparation.

The ranking of shade tree species by farmers from first to the fourth choice showed that majority of farmers (64%) preferred *T. superba* as shade trees on their cocoa farms, 24%, and 12% of farmers selected *K.anthotheca* and *M. excelsa* as their second and third preferred shade tree species on their farms respectively. *Triplochiton scleroxylon* was the least preferred by farmers as the majority of farmers (90%) selected it for the fourth choice. The majority of farmers preferred shade tree species in the order of *Terminalia superba*, *Khayaanthotheca*, *Melicia excelsa* and *Triplochiton scleroxylon* (Table 6).

Farmers' perception of the effects of shade trees on cocoa

The majority of farmers indicated that they maintained shade trees on their farms mainly (i) to provide shade for cocoa seedlings (54%), (ii) to improve microclimatic conditions (12%) and (iii) to improve soil fertility (10%) (Table 7). The major concern of the farmers about shade trees were, reduced sunlight and air circulation (30 %), allelopathic effects (26 %), reduced yield (20%) and host for pests and disease (16%) (Table 8).

Discussion

Effect of Aqueous Extract on germination of cocoa seeds

The aqueous extracts of *Khaya anthotheca* (Mahogany), *T. superba*, *Triplochiton scleroxylon* (Wawa) and *Melicia Excelsa* (Odum) hindered the germination of cocoa seeds but the degree and pattern of their effect depend on their concentration. Allelopathic compounds inhibit seed germination by inhibiting hydrolyzation of reserve food and cell division (Rice, 1984). According to Oyewale and Khadijat (2019) the presence of saponins, tannins, and polyphenolics in plants could account for suppression of germination and growth in plants. Furthermore, many plants emit saponins into the rhizosphere, which may act as allelopathic substances that suppress the growth of surrounding plants, thus reducing competition for resources (Moses et al., 2014). *T. scleroxylon* contains 12.67% tannins, flavonoids, 0.69% of phenols and 2.23% of saponins (Prohp and Onoagbe, 2012) which could have caused the decline in cocoa germination. This is therefore consistent with the choices made by farmers where *Triplochiton scleroxylon* was the least preferred species. Moreover, Abugre et al. (2014) reported that the extracts of *T. scleroxylon* inhibited the germination of three crops, namely, tomato (Lycopersicum esculentum), pepper (Capsicum annuum) and garden egg (Solanummelongena). Aqueous extracts of roots, stems-bark and leaves of *Melicia excelsa* contain flavonoids, saponins, cardiac glycoside, terpenoid and tannins (Bayani et al., 2009; Areola et al., 2015). Terpenoids which make up the largest and most functionally complex group play a significant role in plant interactions (Chen et al. 2011; Cheng et al. 2007).

Germination of seeds depends on the concentration of aqueous extracts, with greater concentrations expressing greater allelopathic potency than the lower concentrations (Siddiqui et al., 2009). Khan et al. (2008) also showed that aqueous extracts at concentrations of 10, 15 and 20% had an inhibitory effect on wheat germination. Therefore, the decline in cocoa seed germination treated with aqueous extracts of *K. anthotheca*, *T. scleroxylon, T. superba* and *M. excelsa* may be related to the existence of allelochemicals which suppressed the seed germination cycle. El-Khatib (1997) suggested that the inverse relationship between seed germination and allelopathic inhibition may be due to reduced water uptake. The lower germination of cocoa seedlings treated with aqueous extracts from the selected shade tree may be partly attributable to the inhibition of water uptake by the presence of some allelochemicals, which prevented the growth of the seed embryo or caused its death (El-Khatib, 1997; Abugre et al., 2011). That notwithstanding, Abugre et al. (2011) reported that leaf extracts of *T. superba* promoted germination of seeds of *Zea mays* by 2.5%; our results on the effects of aqueous extracts of *T. superba* on cocoa seed germination are contrary to this, possibly because allelopathic effects are species-specific.

T. scleroxylon is the most inhibiting species as it recorded the lowest level of germination compared to the other three species selected for this study. Higher concentrations (45 g / lit.) resulted in the highest suppression of cocoa seed germination. The decrease in cocoa seed germination due to allelopathic stress of various aqueous extracts may be attributed to numerous defects of metabolic function, the seed imbibition capacity, and embryonic defects (Maharjan et al., 2007; Chon and Nelson, 2010).

The effect of aqueous extract of the various concentrations of shade trees on the growth of cocoa seedlings

Effects on dry biomass

aqueous extracts of *T. superba* reduced dry biomass with increasing concentration as reported by Bhatt et al. (1997) and Sisodia and Siddiqui (2009). Specifically, Bhatt et al. (1997) found that the aqueous extracts from *Terminalia spp*. suppressed the growth of *Eleusine coracana, Brassica campestris, Horduem vulgare*, and *Glycine max* and their dry biomass whiles Sisodia and Siddiqui (2009) reported that germination and growth inhibition efficiency increased with increasing amounts of various aqueous extracts. Naeem et al. (2012), Oudhia (2001) and Scrivanti (2010) attributed suppression in seed germination and growth of seedlings of the crops they investigated to allelochemicals in plant extracts. Seedling growth inhibition could probably be due to the induction of growth-inhibiting hormones. Bhatt et al. (1997) suggested that the presence of gallic acid, ellagic acid, ethyl gallate, galloyl glucose and chebulagic acid in the aqueous extracts of *Terminalia spp.* inhibited the growth of the crop seedlings they assessed and this resulted in reduced dry biomass. It is therefore possible that the aqueous extracts of *T. superba* contained growth inhibitors which hindered the growth of cocoa seedlings and this resulted in reduced dry biomass. Several authors (Ali-Smith, 2009 and Bukar et al., 2009) have suggested that leaves of certain plants contain allelochemicals such as tannins, saponin, steroids which inhibits plant growth. Azza (2016) also established that the leaf extracts of *R. stricta* inhibited the height of *Viciafaba, Triticum aestivum*, and *Hordeum vulgare.* Furthermore, Randhawa et al. (2002) reported that the root and shoot length of *Trianthema portulacastrum* was decreased by a greater concentration of sorghum aqueous extracts. *T. scleroxylon* and *M. excelsa* aqueous extracts did not affect the dry biomass of cocoa seedlings even though they significantly affected germination of cocoa, possibly because allelochemicals are organ-specific and species-specific.

Effects on root growth

the aqueous extracts of *T. scleroxylon* increased the root length of cocoa seedlings. This finding is consistent with Abugre and Quashie-sam (2010) who reported that maize root and stem length increased with increasing concentrations of aqueous extracts. Allelopathic interactions can produce beneficial effects as it is the case in our finding that *T. scleroxylon* extracts promoted root growth. This finding also converges with Tefera (2002), who suggested that *Parthenium hysterophorus* aqueous leaf, tribal, heart, and flower extracts stimulated the development of the *Eragrostis tef* seedling. Since roots are sensitive to chemical processes, they can react more quickly. Enhanced root growth may be attributed to increased cell replication and growth hormone enhancement or supply of limiting nutrients. The allelochemicals possibly triggered the production and synthesis of growth specific hormones such as auxins. The radicle, which grows into the main root, allows the seed to absorb and transport water and salts to the shoot and leaves of the seedlings for photosynthesis and growth. The positive effects of *T. scleroxylon* extracts on the roots of cocoa seedlings may enhance their early establishment, survival and growth. Generally, in aqueous extract experiments, the reported inhibitory effect is due to pH modification, which raises questions about allelopathy and its ecological nature and significance (Conway et al., 2002; Sisodia, 2008). On the other hand, the root length of cocoa seedlings was not significantly affected by aqueous extracts of *K. anthotheca, M. excelsa*, and *T. superba*; this is contrary to the findings of Abugre et al. (2011) who reported that root and leaf extracts of *T. superba* hindered radicle growth of *Vigna unguiculata, Lycopersicon esculentum* and *Zea mays*. Our results also diverge from Khan et al. (2008), which showed that aqueous extracts at concentrations of 10, 15, and 20% had inhibitory effect on some agricultural crops. Furthermore, Khan et al. (2012) reported that the aqueous extracts from various seedlings of *Parthenium hysterophorus* had significant inhibitory consequences on the root and stem lengths of four wheat cultivars. Allelochemicals are both species-specific and organ-specific; different allelochemicals have different sites of action in different parts of a plant hence different species and organs vary in their sensitivity to allelochemicals (Mahajan *et al.*, 2007; Macias *et al.*, 2004). Moreover, the extent of allelopathic inhibition depends on the concentration of the plant extracts. This accounts of the varied response of the roots of cocoa seedlings to the aqueous extracts of the selected shade tree species.

Effects on shoot length

the aqueous extracts of *Khaya anthotheca* reduced the shoot length of cocoa seedlings and higher concentrations of its aqueous extracts had similar effects on the shoot length of cocoa seedlings (Table 4). The inhibitory effects of some plant extracts on plumule or radicle length may be associated with the occurrence of allelochemicals such as tannins, wax, flavonoids, and phenolic acids (Fag and Stewart, 1994; Mahajan *et al.*, 2007; Macias *et al.*, 2004). Randhawa et al. (2002) reported that high concentration of sorghum aqueous extracts decreased *Trianthema portulacastrum* root and shoot length. Ashrafi et al., (2008) also stated that allelopathic impact in all sunflower aqueous extracts accelerated as the concentration increased. Our results also partly agree with the findings of Khan et al. (2008) who showed that an increase in aqueous extract concentrations increased the inhibitory effect on some agricultural crops. A decrease in shoot length of cocoa seedlings can be deduced from the occurrence of phytotoxic compounds in these aqueous extracts from tree species and the display of inhibitor impact on the growth parameter (Javaid and Anjum, 2006). Therefore, the presence of allelochemicals in the extracts of *Khaya anthotheca* were possibly able to inhibit the synthesis of growth hormones, thus, limited cell division and differentiation resulting in reduced shoot growth.

Generally, aqueous extracts of *T. scleroxylon, T. superba* and *M. excelsa* at all concentrations under this study did not affect the shoot length, except at higher concentrations (45g/lit) and lower concentrations (15g/lit) for *T. superba* and *M. excelsa*, respectively, where reduced shoot length growth was observed (Table 4). Our results diverge from Abugre et al. (2014) who indicated that aqueous extracts of *T. scleroxylon* adversely affected the shoot growth of tomato (Lycopersicum esculentum), pepper (Capsicum annuum) and garden egg (Solanummelongena). Furthermore, our findings are in contrast with previous researchers such as Tefera (2002), Yawer et al. (2007), Sisodia and Siddiqui (2009) and Khan et al. (2011) who found that greater degree of inhibition ensued with the leaves extracts at higher concentrations. That notwithstanding, our results are not entirely different from these authors since at the highest treatment level of 45g/lit, the aqueous extracts of *T. superba* suppressed the growth (shoot) of cocoa seedlings.

- **Farmers' perception of shade trees in cocoa farms**

Farmers had a mixed perception about shade trees on cocoa farms. They perceived shade trees as being important for three key ecosystem services namely, shade for cocoa, microclimate amelioration and maintenance of soil fertility possibly through litterfall and decomposition (Asare and Anders, 2016; Tscharntke et al., 2011; Asigbaase et al., 2021b). On the other hand, farmers viewed shade trees as having negative effects on light penetration and air circulation and cocoa yield (Asare 2005; Asare and Anders, 2016). Ong et al. (2004) reported that shade trees are considered to have a detrimental impact on cocoa plant growth and yields; a view the farmers in our study also held. Additionally, they perceived shade trees as having allelopathic effects and being hosts for pest and disease (Anim-Kwarpong, 2003; Asare 2005; Asare and Anders, 2016). Consistent with this perception, Akrofi et al. (2003) who found out that excessive shade has negative allelopathic effects on cocoa farm influences disease and pest status of cocoa farms.

Vandenbelt et al. (1990) showed that tree roots often exploit the crop root region for nutrients and water. This could be mainly so for shade tree species whose roots are shallow with the horizontal distribution. According to Vandenbelt et al. (1990), the basic model depicted in most agroforestry literature of trees as complementary and interconnected with other crops and plants may be used with caution. The combinations of trees and crops may display more extensive niche differentiation than would be anticipated from their rooting forms in monoculture because of reactions to reduced water and nutrient obtainability in upper soil layers as a result of resource consumption by companion crops (Sinclair *et al.*, 1994). Contrary to the assertions of Vandenbelt et al. (1990) and Sinclair *et al.* (1994), farmers in our study did not view competition with cocoa trees for water and nutrients as a major issue.

Notwithstanding farmers' mixed perception about shade trees, they were willing to integrate shade trees into their cocoa farms as they requested, received and planted shade tree seedlings supplied by the Forestry Commission of Ghana. This willingness may be a reflection of the perception that the positive effects of shade trees may compensate for or outweigh their negative effects. The most preferred shade by the farmers was *Terminalia superba* yet our results show that aqueous extracts from this tree species resulted in reduced cocoa seed germination and biomass (Tables 2 and 5). This calls for further research and interventions to ensure recommended or preferred species are indeed beneficial for sustainable cocoa production.

Conclusions

Based on the findings, we concluded that *Khaya anthotheca, Melicia excelsa, Terminalia superba* and *Triplochiton scleroxylon* suppressed the germination of cocoa and higher concentrations showed mixed results, which are always lower than the control. Higher concentrations of *K. anthotheca* reduced cocoa seed germination while higher concentrations of *T. scleroxylon, M. excelsa*, and *T. superba* generally did not increase inhibition of the germination of cocoa seeds. Whereas the aqueous extracts of *T. superba* reduced the dry biomass of cocoa seedlings and the aqueous extracts of *K. anthotheca* hindered the shoot growth of cocoa, the aqueous extracts of *T. scleroxylon* enhanced the growth of the root length of cocoa seedlings. Generally, the aqueous extracts of *M. excelsa* did not adversely affect the dry biomass, shoot length and root length of cocoa seedlings. Farmers at the research areas preferred *Terminalia superba* on their farms to other species. Their reason being that it has a positive effect on cocoa seedlings. Farmers keep shade trees on their farms purposely to provide shade for cocoa seedlings. We recommend the use of *T. scleroxylon* and *M. excelsa* on cococa farms as these species either promoted or had no adverse effects cocoa seedling growth.

Declarations

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Funding Statement

No funding was secured for the study.

Ethics Statement and Consent to participate

No ethical approval was sought for the study, however, ethical issues were addressed during the research. No formal permission was sought in obtaining the plant species from Modified ‘Taungya’ Plantations established by the Forestry Commission. One of the authors was a Manager of these plantations and also a staff of the Forestry Commission. Farmers who participated in the study were informed of the importance of the study and their right not to participate. A verbal consent was obtained from participants before administration of the questionnaire.

Consent to publish declaration

The authors grant permission for the publication of their manuscript.

Competing interest

The authors declare that there is no competing interest.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Clinical Trial number

This is not applicable

Author Contribution

1) S. A. Conceived the idea, designed the analysis, wrote the manuscript, laid the experiment, contributed to analysis and the lead2) E. A. Collected the data, wrote the paper, contributed data and analysis tools, contributed to laying of experiment3) S. N. Contributed data analysis and Laying of experiment4) M. A. Performed the analysis, reading of manuscript5) A. A. A. Performed the analysis, reading of manuscript

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Tables

Tables 1 to 8 are available in the Supplementary Files section.

Figures

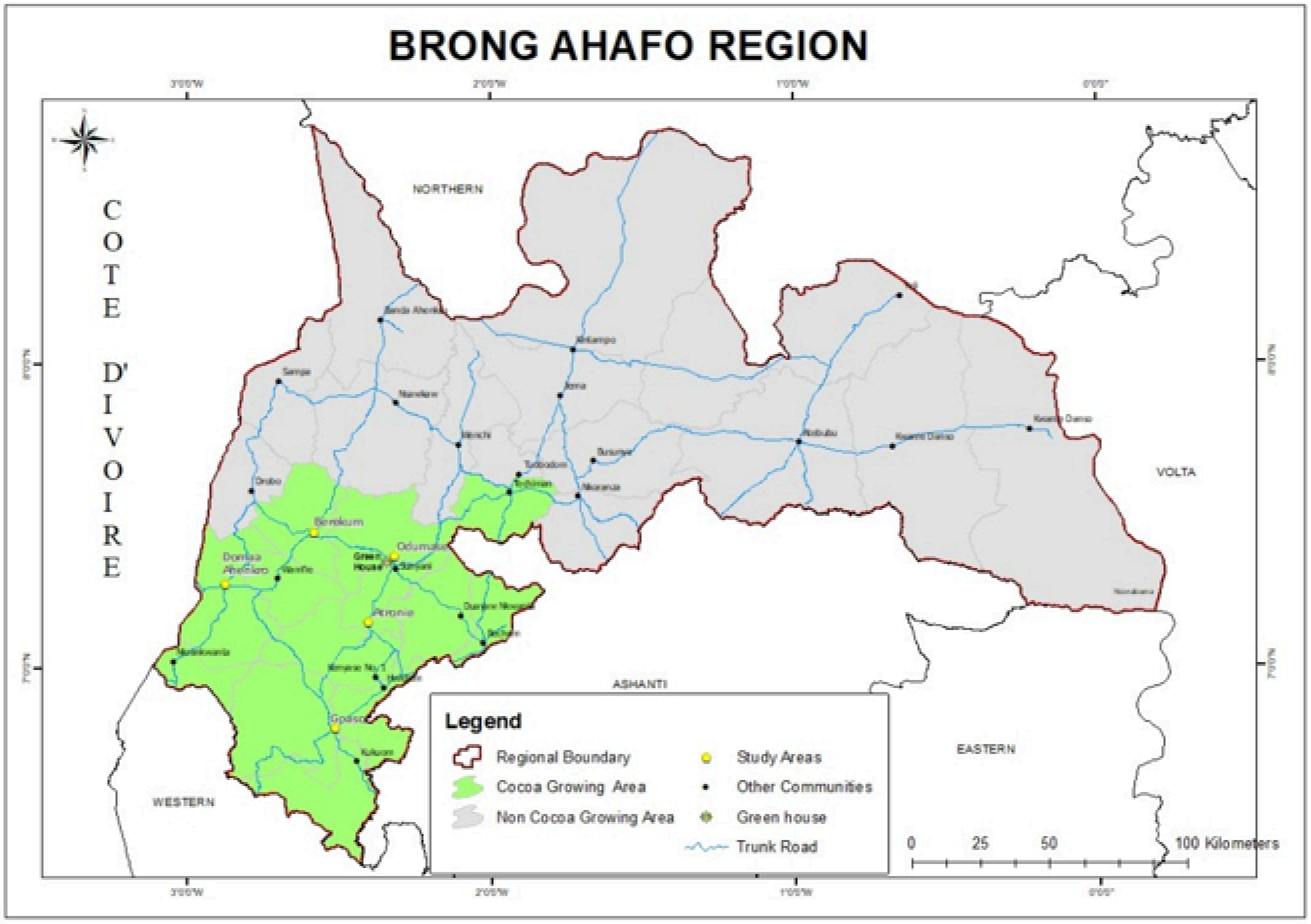

Figure 1

The map of the cocoa growing districts

Supplementary Files

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