Original Research Article

Perceived Climate Resilience and Adoption of Cocoa Agroforestry in the Forest-Savannah Transition Zone of Ghana

ABSTRACT

Aims: Agroforestry is globally acknowledged as an essential component of climate-smart agriculture. Nevertheless, agroforestry adoption is low, and research is lacking on how farmers perceive the climate-related benefits of agroforestry and the implications of such perceptions on adoption. This paper assessed farmer perspectives on the effectiveness of agroforestry in enhancing the climate resilience of cocoa, and the extent to which such perceptions (in conjunction with socioeconomic factors) influence farmers' decision to adopt cocoa agroforestry or otherwise.
Study Design: A cross-sectional survey design involving households practicing different cocoa landuse systems (agroforestry vs. full-sun monoculture) was used.
Methodology: Data were collected using structured questionnaire administered to 240 randomly selected cocoa-farming household heads.
Place and Duration of Study: The study took place in 12 rural communities in the Forest-Savannah Transition Zone of Ghana from March to September 2017.
Results: Findings indicated that while farmers unanimously acknowledged the effectiveness of cocoa agroforestry in enhancing resilience to excessive dry season temperatures, their perceptions in terms of resilience to drought differed, and were largely shaped by the kind of shade trees integrated. Overall, the majority of household heads perceived agroforestry to be the most beneficial strategy for enhancing the climate resilience of farmers. This perception significantly influenced households' decision to adopt cocoa agroforestry, in conjunction with socioeconomic factors such as social network, sex of the household head, sex distribution of the household, and off-farm income.
Conclusion: Social network and farmers' perception of the effectiveness of agroforestry in enhancing climate resilience are the key determinants of cocoa agroforestry adoption in the FSTZ of Ghana. Farmers who perceive agroforestry to be the most beneficial climate-resilient strategy in agriculture are more likely to adopt cocoa agroforestry. Social network can be used to enhance cocoa agroforestry adoption by serving as an effective communication channel for spreading information about the climate-related benefits of shade trees among farmers.

Keywords: Climate resilience; farmer perceptions; cocoa; agroforestry adoption; social network; Ghana

1. INTRODUCTION

Climate change has become a significant source of risk for agriculture [1], especially in cocoa production where a narrow range of hot humid climatic conditions is required for good growth and yield [2,3]. The forest-savannah transitional areas of West Africa's cocoa belt are becoming progressively vulnerable to seasonal droughts and maximum temperatures approaching the physiological tolerance limit of cocoa [4,3]. In Ghana, it is even predicted that the climate may be entirely unsuitable for cocoa by 2080 [5]. On the other hand, cocoa production is providing a positive feedback for climate change by serving as a major source of carbon emissions through deforestation [6].

Agroforestry (the integration of shade trees) has received considerable attention in the literature as an effective climate-resilient strategy in cocoa production [7,8,9]. Nevertheless, cocoa agroforestry adoption is low [10,8] as farmers increasingly switch to full-sun monoculture [10,9,11]. In improving understanding of farmers' agroforestry adoption behaviour, several studies have extensively examined the influence of socioeconomic factors on adoption [12]. For example, there is ample evidence that agroforestry adoption is positively influenced by the age [13,14], education level [15,14], gender (being a male) [13,8], farming experience [16], marital status [14], and ethnicity [17] of the household head. The likelihood of agroforestry adoption is also reported to increase with land ownership [18,16], agricultural labour size [19], proportion of males in a household [20], farm and off-farm income [18], food security [21], access to extension [18,8], access to climate information from official sources [22], and membership of farmers' associations [22].

There is, however, limited empirical evidence on the influence of farmer perceptions on agroforestry adoption [12]. It is imperative to bridge this knowledge gap because farmers often perceive the benefits of agroforestry differently from researchers and extension staff, and such as disjuncture in perspectives could undermine adoption if overlooked [12]. In general, most of the studies on climate change solutions in the agricultural sector have ignored farmers' perceptions [23], despite the fact that farmers are on the frontlines of climate change impacts [24]. There is therefore a paucity of literature on farmers' perspectives on climate change issues [25,26]. In the Forest-Savannah Transition Zone (FTSZ) of Ghana for instance, several authors have recommended agroforestry as an effective strategy for enhancing the resilience of cocoa production to marginal climatic conditions [27,28], but research is lacking on how farmers perceive the climate-related benefits of agroforestry and whether such perceptions significantly influence their agroforestry adoption decisions. It is therefore imperative to jointly consider farmer perceptions and socioeconomic factors in understanding and enhancing agroforestry adoption [12] as a climate risk management strategy. Several authors (e.g. Jarawura, [29], Roberts *et al*. [30]) have also underscored the need for climate change solutions in agriculture to build on local perspectives, since local communities have a detailed knowledge of their environment, and have historically improvised strategies to cope with climate change.

This paper therefore assesses farmer perceptions of the effectiveness of agroforestry in enhancing the climate resilience of cocoa, and the extent to which such perceptions (in conjunction with socioeconomic factors) influence farmers' decision to adopt cocoa agroforestry or otherwise in the FSTZ of Ghana. The paper focuses on the FSTZ of Ghana because cocoa production in the zone is highly vulnerable to climate change compared to the mainstream production zone, which is the High Forest Zone [27]. The FSTZ of Ghana used to exhibit good climate suitability for large scale cocoa production, but has already become marginal for cocoa due to multiplicity of risk factors including prolonged drought, increasing temperature, and recurrent wildfires [27,31]. Cocoa farming in the zone is characterised by very low yields [27] and high crop mortality due to excessive dry season temperature and prolonged droughts [32]. These factors make the FSTZ an ideal setting for furthering understanding of the climate resilience of cocoa agroforestry from farmers' perspective. Climate resilience has been defined as "the ability of individuals and communities to cope with, and adapt to, the social, political, economic and ecological challenges precipitated by a changing climate and climatic events" [32]. According to Folke *et al*. [33], resilience is the flipside of vulnerability. A system is therefore said to be more resilient if it is less vulnerable [34].

Due to the increased need for farmers to adapt to harsh climatic conditions in the cocoa sector, and particularly in the FSTZ [27,2,3], this paper hypothesises that farmers' perception of the effectiveness of agroforestry in enhancing climate resilience is a key determinant of their decision to adopt agroforestry or otherwise. Farmers who perceive agroforestry to be the most beneficial climate-resilient strategy in agriculture are expected to be more likely to adopt cocoa agroforestry. Thus, cocoa agroforestry adoption is expected to be jointly determined by socioeconomic factors and farmer perceptions of the climate resilience of agroforestry systems [12]. This argument is consistent with the Diffusion of Innovations Theory [36], which underscores the significance of perceived relative advantage of an innovation on adoption. This paper conceptualises perceived relative advantage in terms of climate change because of the high climate vulnerability of cocoa production and the increasing need for farmers to adapt. The diffusion theory [36] and the empirical literature [37,38] also emphasise the importance of social network as an effective communication channel for spreading knowledge of an innovation, and enhancing adoption. Members of a given social network are said to be homophilous because they share similar attributes such as beliefs and social status [36]. Homophilous individuals are theorised to promote diffusion among each other because their homophily (similarity) allows them to engage in more effective communication, which leads to greater knowledge gain and attitudinal change [36]. Accordingly, a social network of friends and relatives is expected to positively influence cocoa agroforestry adoption in the FSTZ by serving as an effective communication channel for spreading information on the climate-related benefits of shade trees among farmers. In sum, findings highlight potential entry points for enhancing cocoa agroforestry adoption from the climate perspective, and enabling it to contribute adequately to climate resilience in highly vulnerable areas.

2. MATERIAL AND METHODS

2.1 Study Area

The study was conducted in 12 rural farming communities in the Techiman North District (7.63° N, 1.91° W), Wenchi Municipal (7.74° N, 2.10° W), Mampong Municipal (7.05° N, 1.40° W) and Offinso North District (7.39° N, 1.95° W) in the FSTZ of Ghana (Figure 1). The selected communities were Asueyi, Aworowa and Krobo in the Techiman North District; Tromeso, Ayigbe and Mallamkrom in the Wenchi Municipality; Atonsuagya, Adidwan and Abuontem in the Mampong Municipality; and Seseko, Sraneso No.2 and Tanokwaem in the Offinso North District.

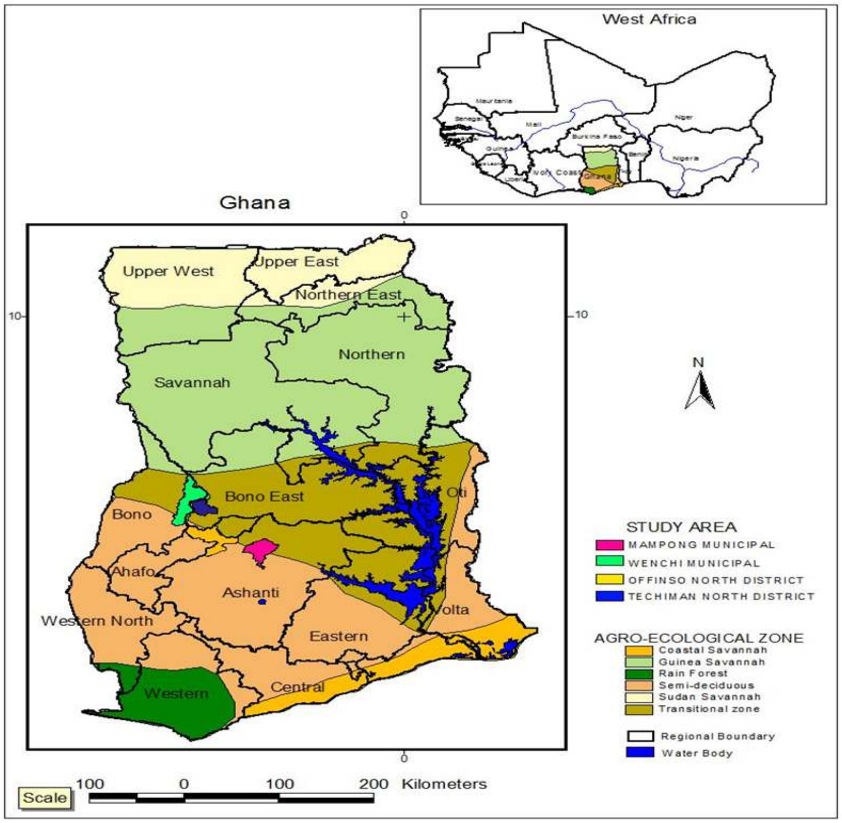

Figure 1. Regional and agroecological map of Ghana showing the study districts and municipalities (Adapted from Rhebergen *et al*., [39])

The vegetation of the area is a blend of the Dry Semi-deciduous forest in the High Forest Zone (HFZ) and the Guinea Savannah zone to the north. The landscape is transitional in nature and is characterised by continuous conversion of forest into grassland. The area experiences total annual rainfall of 1100 to 1400 mm, and an average temperature of 17 to 33ºC [40]. Crop farming is the main source of livelihood, with maize being the dominant crop.

2.2 Data Sources and Methods of Data Collection

Two hundred and forty cocoa farming households were randomly sampled from the 12 rural communities indicated in Section 2.1. The household was used as the unit of analyses because risk management strategies begin with decisions at the farm and household levels [41]. A household was defined as 'a group of people who lived together, owned the same productive resources and fed from the same pot' [42]. That occasionally consisted of just one person. Data was collected using a structured questionnaire administered to 240 household heads. Household heads were selected as the primary respondents because they are generally the main decision makers at the household level in the study communities. The questionnaire captured the socioeconomic characteristics of households and household heads; cocoa landuse system adopted; and household heads' perceptions of the effectiveness of agroforestry in enhancing the climate resilience of cocoa. Climate resilience is conceptualised from farmers' perspective in this study because farmers are on the frontlines of climate change impacts [24], and hence, capable of observing changes in their resilience to such impacts. Similar to

Abdulai *et al*. [43], cocoa landuse systems were dichotomised into agroforestry and full-sun systems based on whether or not households had integrated multipurpose trees and or shrubs into their cocoa farms at the time of the study. The questionnaire included open-ended questions which allowed additional remarks made by respondents to be captured. Transect walks and farm visits were also used to directly observe cocoa landuse practices adopted by farmers. Data were collected for six months; from March 2017 to September 2017.

2.3 Data Analyses

Data was analysed using SPSS (v.20). Factors influencing cocoa agroforestry adoption were assessed using binary logistic regression, after taking the necessary data requirements into consideration. Theoretically, a binomial logistic regression model with a dependent variable (Y) and explanatory variables "X_1, $X_{2,}$ ....Xn" is estimated as:

$$logit(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_n X_n + \varepsilon \text{------} (1)$$

Where β_0 is the constant (intercept), β_1 is the coefficient for X_1, and so forth, and ε represents the sample errors or residuals. The model was specified as follows:

$$ADOPT=\beta_0+\beta(SEX)+\beta(AGE)+\beta(EDU)+\beta(MAR)+\beta(ETHNIC)+\beta(FEX)+\beta(COEX)+\beta(PERC)+\beta(LAND)+\beta(LAB)+\beta(SEXD)+ \beta(INC)+\beta(OFF)+\beta(FOOD)+\beta(MEMB)+\beta(NETWORK)+\beta(INFO) + \beta(EXT) + \varepsilon \text{------} (2)$$

ADOPT is a binary outcome variable representing cocoa landuse system adopted (1 if agroforestry; 0 if full sun). The predictor variables are socioeconomic and perception-related factors drawn from the literature (Section 1.0). SEX is a binary variable (1 if the household head is a male; 0 if female). AGE is the age of the household head in years measured as continuous variable. EDU is a dichotomous variable representing formal education of the household head: 1 if completed a minimum of primary education; 0 if otherwise. A minimum of primary qualification is used as the reference because primary education, according to the International Standards Classification of Education [44], provides a solid foundation for learning and understanding core areas of knowledge. MAR is a dummy variable donating the marital status of the household (1 if married; 0 if otherwise). ETHNIC is the ethnicity of the household head conceptualised as a binary variable (1 if native; 0 if migrant). FEX and COEX donate farming and cocoa farming experience of the household in years respectively. PERC is a dichotomous variable. It takes a value of 1 if agroforestry was perceived by the household head to be the most beneficial climate-smart strategy for farmers; 0 if otherwise. LAND assumes a value of 1 if the household owned the land used to grow cocoa; 0 if otherwise. LAB is a continuous variable donating number of household members that provided farm labour. SEXD represents sex distribution of the household measured as a dummy variable (1 if the proportion of males exceeded that of females; 0 if otherwise). INC denotes gross household income from all crops sold in the last 12 months (2016/17) and measured in thousands of Ghana Cedis. OFF takes a value of 1 if a household had off-farm income; 0 if otherwise. FOOD represents food security status of the household measured as a dummy variable using the USDA Food Security Core Module [45]. Following Bickel *et al*. [45], households that scored 0.0 to 2.2 based on the USDA Core Module were classified as food secure and coded 1; those that scored beyond 2.2 were coded 0 (i.e. food insecure). MEMB indicates membership of farmers' association by any household member measured as a dummy variable (1 if any; 0 if none). NETWORK was conceptualised as a dummy variable representing social network (friendship and or family ties) of the household head with cocoa agroforestry adopters (1 if yes; 0 if none). INFO and EXT indicate regular access to climate-related information and cocoa extension using the last 12 months (2016/17) as a benchmark (1 if yes; 0 if no). The model predicts how each of the independent variables influences the odds of agroforestry adoption in cocoa households. Descriptive statistics of variables included in the model can be found in Appendix 1.

3. RESULTS AND DISCUSSION

3.1 Farmer Perceptions of the Effectiveness of Agroforestry in Enhancing the Climate Resilience of Cocoa Production

The vast of majority of households (82.50%) stated to be practising cocoa agroforestry, while 17.50% indicated to be growing cocoa in full sun (i.e. without shade trees). Most of the household heads (79.40%) perceived the climate of their communities to have changed over the last 30 years. The perceived changes reported were excessive dry season temperature (38.79%), erratic rainfall pattern (27.80%), prolonged droughts (23.28%), stronger winds (9.91%), and decreasing humidity (0.22%). These climatic changes, from farmers' viewpoint, had created a hot and dry climate, which was exacerbating heat and moisture stress on cocoa, and resulting in abnormally low yields, high crop mortality, and increased incidence of pests and diseases. Farmers unanimously observed that cocoa agroforestry was effective in enhancing resilience to excessive dry season temperatures by providing adequate shading. It was observed during transect walks and farm visits that while cocoa plants under shade trees generally maintained green and broad leaves, those in full sun generally had desiccated and thin leaves. Approximately 44% of full-sun households (FSHs) were therefore considering agroforestry in response to high crop mortality caused by harsh temperature.

There was, however, a clash of perspectives among farmers on the effectiveness of agroforestry in enhancing resilience to drought. Agroforestry households (AGHs) generally perceived shade trees in cocoa farms to be effective in enhancing soil moisture conservation against drought. *Alstonia boonei* was particularly noted by farmers to be highly effective for enhancing the resilience of cocoa to drought. Farmers observed that *A. boonei* supplied the soil with adequate amount of water that could even be seen around it and under the cocoa trees near it. Some farmers therefore popularly referred to it as the 'rain tree'. On the other hand, FSHs argued that agroforestry rather renders cocoa plants more vulnerable to drought, thereby leading to lower yields. The perceived vulnerability to drought was attributed to below-ground competition for water from shade trees, which was thought to deprive cocoa plants of adequate water. Farmers who held that view commonly referred to the 2015/16 drought as a test case for whether shade-grown cocoa should be the way forward under the current climate of declining rainfall. One farmer remarked "*during last year's drought, a lot of cocoa plants died….but we observed that cocoa under shade trees were mostly affected because the trees outcompeted the cocoa for the little amount of water that was left in the soil"*. Some FSHs even maintained that cocoa agroforestry was only appropriate in the olden days when the climate was very wet, because the amount of soil moisture was high enough to mask the effects of below-ground competition. *Antiaris toxicaria* was particularly noted to be highly competitive for water. FSHs observed that *A. toxicaria* renders the soil dry and compacted, making it difficult for cocoa plants around it to survive or bear sufficient fruits. During farm visits, some farmers were even observed to be eliminating *A. toxicaria* from their cocoa farms by debarking the trunk and applying certain weedicides on the debarked surface.

3.2 Perceived Effectiveness and Cocoa Agroforestry Adoption from the Climate Resilience Standpoint

Farmers' perceptions of the benefits of agroforestry in terms of climate resilience, were found to be quite influential in their agroforestry adoption decisions. Both AGHs and FSHs justified their decision to adopt agroforestry or otherwise largely from the climate standpoint. In the case of FSHs, farmers cited both climate and non-climate reasons for not adopting agroforestry (Figure2), but the main reason (76.19%) was the perception that shade trees increase vulnerability to drought and low yield. In contrast, approximately 86% AGHs attributed their decision to integrate shade trees to the hot and dry climatic conditions of the FSTZ, and about 41% of the 86% confirmed they would not have adopted agroforestry if their farms were located in the HFZ where climatic conditions are less harsh. Overall, more than half of household heads (57.90%) perceived agroforestry to be the most beneficial climate-resilient strategy for farmers[1].

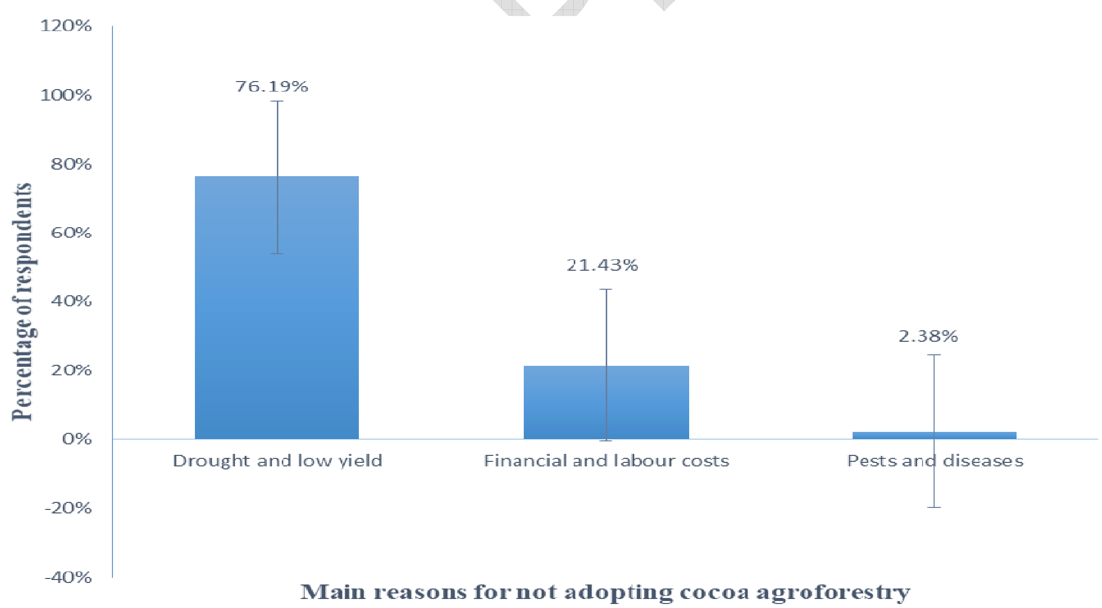

Figure 2. Climate and non-climate reasons for not adopting cocoa agroforestry in the Forest-Savannah Transition Zone of Ghana (*n=42*)

[1] The remaining 42.10% cited non-agroforestry strategies such as slash and mulch (zero burning), mechanised irrigation, intensive use of fertiliser, temporary shading using plantain, cashew farming, and livestock farming.

Binary logistic regression was used to assess the extent to which farmers' perception of agroforestry as the most beneficial climate-resilient strategy (in conjunction with socioeconomic factors) influences their decision to adopt cocoa agroforestry or otherwise. The model excluded three households from the analysis because they were unable to estimate their crop income. One case of extremely high studentised residual (-9.832) was considered a significant outlier, and was removed from the analysis due to substantial changes in the regression coefficients when the analysis was run without it [46]. Linearity of the continuous predictor variables with respect to the logit of the outcome variable was assessed following Box-Tidwell [47]. All the continuous variables were linearly related to the logit of the dependent variable (p>0.05). No multicollinearity was detected. The highest variance inflation factor was 2.097. The regression results, goodness of fit, and model performance statistics are summarised in Table 1.

Table 2. Perception and socioeconomic factors influencing cocoa agroforestry adoption by smallholder households in the Forest-Savannah Transition Zone of Ghana

Explanatory Variables	Coefficient (β)	S.E	Wald	df	*P*	Odds Ratio	95% CI for Odds Ratio	
							Lower	Upper
SEX(1)	2.165*	.948	5.218	1	.022	8.714	1.360	55.837
AGE	-.007	.027	.063	1	.802	.993	.941	1.048
EDU(1)	-2.070**	.770	7.235	1	.007	.126	.028	.570
MAR(1)	-.823	.816	1.019	1	.313	.439	.089	2.172
ETHNIC(1)	-.831	.736	1.276	1	.259	.436	.103	1.842
FEX	-.018	.028	.438	1	.508	.982	.930	1.037
COEX	.005	.040	.016	1	.900	1.005	.929	1.087
PERC(1)	1.970***	.542	13.222	1	.000	7.171	2.480	20.737
LAND(1)	.005	.821	.000	1	.996	1.005	.201	5.022
LAB	-.104	.124	.702	1	.402	.901	.707	1.149
SEXD(1)	1.154*	.559	4.262	1	.039	3.172	1.060	9.491
INC	.004	.025	.027	1	.870	1.004	.956	1.055
OFF(1)	1.414*	.565	6.256	1	.012	4.112	1.358	12.451
FOOD(1)	.061	.514	.014	1	.906	1.062	.388	2.908
ASSO(1)	.174	.552	.100	1	.752	1.190	.404	3.511
NETWORK(1)	2.917****	.526	30.795	1	.000	18.477	6.596	51.759
INFO(1)	-.537	.583	.848	1	.357	.585	.187	1.832
EXT(1)	.104	.583	.032	1	.858	1.110	.354	3.487
Constant	.025	1.539	.000	1	.987	1.025		

Goodness of Fit and Model Performance Statistics

Number of Observations	236
Hosmer and Lemeshow P Value	0.098
Deviance (-2 Log Likelihood)	121.61
Likelihood Ratio (LR) Chi square	96.33****
Classification accuracy of baseline model	82.60%
Classification accuracy of fitted model	91.90%
Nagelkerke (Pseudo) R^2	0.556

*Significant at 5%, **Significant at 1%, ***Significant at 0.05%, ****Significant at 0.00005%

The fitted model was highly significant, (χ^2 (18) = 96.33, p < .001) and explained 55.60% of the variance in cocoa agroforestry adoption. Its classification accuracy (91.90%) was an improvement of the null model (82.60%). Six out of the 18 explanatory variables were statistically significant. These were household heads' perception of agroforestry as the most beneficial climate-resilient strategy for farmers (p < .001) and socioeconomic factors such as social network (friendship or and family ties) of the household head with cocoa agroforestry adopters (p < .001), education level of the household head (p=.007), sex of the household head (p=.022); sex distribution of the household (p=.039) and off-farm income (p=.012). Social network was the most significant predictor followed by perception of agroforestry as the most beneficial climate-resilient strategy. Social network increased the odds of cocoa agroforestry adoption by 17.477 (1747.70%). The odds also increased by 6.171 (617.10%) when agroforestry was perceived by the household head to be the most beneficial climate-resilient strategy for farmers. Households with off-farm income and greater proportion of males than females were 4.112 and 3.172 times more likely to integrate shade respectively. Male-headed households were also 8.714 times more likely to adopt agroforestry compared to their female-headed counterparts. In contrast, formal education of the household head reduced the odds of adoption by 0.874 (87.40%). The remaining socioeconomic variables (age, marital status, ethnicity, farming and cocoa farming experiences, land ownership, agricultural labour size, crop income, food security status, membership of farmers' association, and access to climate-related information from official sources, and cocoa extension) did not significantly influence cocoa agroforestry adoption.

3.3 Discussion

Contrary to the literature that cocoa agroforestry adoption is low and cocoa is increasingly being grown in full-sun monocultures (Section 1.0), a widespread adoption of cocoa agroforestry was observed in the FSTZ due to a greater need for farmers to adapt to harsh climatic conditions. This finding is consistent with Abdulai *et al.* [27] who observed that the medium shade cocoa agroforestry system (30% canopy cover) was more abundant in the FSTZ (dry zone) than in the HFZ (mid and wet zones), and was considered by farmers as adaptation to marginal climatic conditions. Consistent with the Meijer *et al*. [12], the logistic regression results strongly suggest that the widespread adoption of cocoa agroforestry in the FSTZ was jointly influenced by perceptions and socioeconomic factors. The significant influence of education level of the household head, off-farm income, sex of the household head, and sex distribution of the household found is in line with the empirical literature [13,14,15,16,17,18,19,20,21,22]. The significant positive influence of social network on adoption is also in accordance with the concept of homophily as underscored by the diffusion theory [36]. Households headed by people with social network were highly likely to adopt cocoa agroforestry probably due to information flow from friends and relatives who might have found cocoa agroforestry to be beneficial from the climate standpoint.

The significant positive influence of household heads' perception of agroforestry as the most beneficial climate-resilient landuse system was probably due to a strong connection between perceived relative advantage of an innovation and adoption, as emphasised by the diffusion theory. This result also implies that climate resilience is of much importance to cocoa farmers in highly vulnerable areas [27,2,3], and hence, quite influential in farmers' landuse decisions. Accordingly, FSHs avoided agroforestry mainly due to the perception that it increases vulnerability to drought and low yield (i.e. not beneficial in terms of climate resilience). Thus, while the relative advantage of agroforestry in enhancing resilience to harsh temperature was acknowledged by both AGHs and FSHs, farmers' perceptions were quite divergent in terms of resilience to drought. The conflicting perceptions reinforce the assertion that the potential benefits of agroforestry are not always realised in practice [48].

Although the drought disadvantage of cocoa agroforestry was perceived by a limited proportion of household heads, it is somehow supported by more recent studies [7,43,49]. For instance, Abdulai *et al*. [43] found in the FSTZ of Ghana that cocoa plants under *Albizia ferruginea* and *Antiaris toxicaria* suffered 100% and 77% mortality respectively during the 2015/16 drought, while cocoa in full sun, suffered only 12% mortality [50]. The authors also found that soil water content in shaded cocoa was lower than in the full-sun system, and attributed that to reduced throughfall and strong competition for soil water due to similar rooting systems of cocoa and shade trees. The perceived negative effect of drought on cocoa bean yield is also supported by the empirical literature [51,11]. The perception that shade trees enhance vulnerability to drought was probably because cocoa farmers in the study area were generally integrating shade trees that were highly competitive for soil water, such as *A. toxicaria*. As found by Abdulai *et al.* [43], *A. toxicaria*, was the tree species commonly maintained by farmers in the study area, although it is not among the species recommended by the Cocoa Research Institute of Ghana (CRIG). This implies farmers generally in the study area generally lacked sufficient knowledge of climate considerations in shade tree selection. Several authors (e.g. Andres *et al*. [10], Nunoo *et al*. [8]) similarly indicate lack of technical knowledge of agroforestry on the part of farmers as one of the main barriers to effective implementation of cocoa agroforestry. Findings further imply that farmers' perceptions of the climate-related benefits of agroforestry were biased towards climate adaptation, as the link to carbon sequestration and climate change mitigation was not emphasised by any of the households. Broadening farmers' perspectives from farm-level adaptation to landscape-level mitigation, and emphasising synergies between mitigation and adaptation may create additional incentives for cocoa agroforestry adoption.

4. CONCLUSION

Social network and farmers' perception of the effectiveness of agroforestry in enhancing climate resilience are the key determinants of cocoa agroforestry adoption in the FSTZ of Ghana. Farmers who perceive agroforestry to be the most beneficial climate-resilient strategy in agriculture are more likely to adopt cocoa agroforestry. Findings suggest that a social network of friends and relatives can be used to enhance cocoa agroforestry adoption by serving as an effective communication channel for spreading information about the climate-related benefits of shade trees among farmers. A comprehensive climate change education for farmers that emphasises synergies between adaptation and mitigation, and diffused through social network is therefore recommended as a potentially effective pathway for enhancing cocoa agroforestry adoption. Findings also imply that while farmers unanimously acknowledge the effectiveness of cocoa agroforestry in enhancing resilience to excessive dry season temperatures, their perceptions in terms of resilience to drought differ and are largely shaped by the kind of shade trees integrated. It would therefore be helpful for climate-smart cocoa agroforestry interventions to tap into farmers' knowledge in identifying, evaluating and promoting shades trees that are climatically-appropriate for cocoa production in specific contexts.

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Appendix 1. Descriptive statistics of independent variables on cocoa agroforestry adoption in the Forest-Savannah Transition Zone of Ghana (*n=236*)

Categorical variables	**n**	**%**
Cocoa Landuse System Adopted		
Full-sun	41	17.37
Agroforestry	195	82.63
Sex of Household Head		
Female	29	12.29
Male	207	87.71
Education Level of Household Head		
Completed at least primary education	172	72.88
Did not complete primary education	64	27.12
Ethnicity of Household Head		
Native	163	69.07
Migrant	73	30.93
Marital status of Household Head		
Married	189	80.08
Not married	47	19.92
Household heads' perception of the most beneficial climate-smart strategy		
Agroforestry	136	57.63
Non-agroforestry	100	42.37
Land ownership status		
Own the land	179	75.85
Does not own the land	57	24.15
Sex distribution		
Males outnumber females	99	41.95
Males do not outnumber females	137	58.05
Access to off-farm income		
Yes	127	53.81
No	109	46.19
Food security status		
Food secure	100	42.37
Food insecure	136	57.63
Membership of farmers' association		
Yes	165	69.92
No	71	30.08
Social network with cocoa agroforestry adopters		
Yes	183	77.54
No	53	22.46
Access to climate-related information		
Yes	144	61.02
No	92	38.98
Access to cocoa extension		
Yes	176	74.58
No	60	25.42
Continuous variables	**Mean ± SD**	
Age of household head (years)	53.86±12.85	
Farming experience of household head (years)	25.03±13.18	
Cocoa farming experience of household head (years)	9.79±7.28	
Number of household members that provide farm labour	3.21±1.96	
Gross annual crop income in thousands of Ghana Cedis	8.61±10.98	