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RESEARCH ARTICLE

Social network to inform and prevent the spread of cocoa swollen shoot virus disease in Ghana

Christian Andres[1,2] • Raphael Hoerler[2] • Robert Home[1] • Jonas Joerin[2] • Henry K. Dzahini-Obiatey[3] • George A. Ameyaw[3] • Owusu Domfeh[3] • Wilma J. Blaser[2] • Andreas Gattinger[1,4] • Samuel K. Offei[5] • Johan Six[2]

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Abstract

The cocoa swollen shoot virus disease is a major factor limiting cocoa (*Theobroma cacao* L.) productivity for West African farmers. The only treatment against this disease is to cut infected trees and replant with disease-free planting material. Research has recommended the prevention measures: (i) cordon sanitaire (leaving 10-m-wide cocoa-free zone around cocoa), (ii) barrier cropping, (iii) using partly tolerant hybrids, and (iv) removing specific alternative host tree species. Here, we evaluate the current adoption of these measures and identify their adoption constraints. We conducted a quantitative survey with 396 farmers in the Eastern and Western Regions of Ghana, held six focus group discussions and hosted a multi-stakeholder validation workshop with 31 key actors in the cocoa value chain. Our results indicate that the adoption of prevention measure against the disease remains limited. Farmers with a more extensive social network (number of family members/close friends who already adopted a particular measure), a larger farm size, more secure land tenure rights, and more knowledge about the measures were more likely to adopt them, especially barrier cropping, hybrid seedlings, and removing alternative host trees. Lack of knowledge about the measures was the single biggest barrier for their adoption, with 51% of the participating farmers not even being aware of any prevention measures. Here, we show for the first time that the social network is the main information source for farmers, which agrees with the finding that the flow of information between farmers and other stakeholders is a critical factor affecting knowledge spread and consequently adoption. Our results provide crucial insights for the elaboration of an implementation action plan to boost the dissemination of feasible prevention measures against the cocoa swollen shoot virus disease in Ghana in order to efficiently cover farmers' needs for information (technical advice) and inputs (access to hybrid seedlings).

Keywords *Theobroma cacao* · Cocoa swollen shoot virus disease · Cordon sanitaire · Barrier cropping · Hybrids · Adoption · Social network · Knowledge · Farm size · Land tenure

1 Introduction

The cocoa swollen shoot virus disease (CSSVD) is a major factor limiting the productivity of cocoa (*Theobroma cacao* L.) for farmers in West Africa. CSSVD is caused by the cocoa swollen shoot virus (CSSV), which belongs to the genus *Badnavirus* (Lot et al. 1991). CSSV causes symptoms such as transient red veins and mottling in young leaves, chlorosis

Christian Andres and Raphael Hoerler contributed equally to this work.

✉ Christian Andres
christian.andres@fibl.org

1 Research Institute of Organic Agriculture (FiBL), Ackerstrasse 113, Postfach 219, 5070 Frick, Switzerland

2 Department of Environmental Systems Science, Swiss Federal Institute of Technology, ETH Zurich, Tannenstrasse 1, 8092 Zürich, Switzerland

3 Cocoa Research Institute of Ghana, P. O. Box 8, New Tafo-Akim, Eastern Region, Ghana

4 Justus-Liebig University Giessen, Karl-Glöckner-Strasse 21C, 35394 Gießen, Germany

5 University of Ghana, P.O. Box LG 25, Legon, Accra, Ghana

in mature leaves and pods, and root atrophy and stunting, as well as root and stem swellings. Highly pathogenic strains cause severe leaf chlorosis, which may result in the rapid death of cocoa trees (Dzahini-Obiatey et al. 2010). Different species of mealybugs spread CSSVD by serving as vectors for CSSV (*Pseudococcidae* spp.), with the most important being *Formicococcus njalensis* (Laing) and *Planococcus citri* (Bigger 1981).

The disease is particularly relevant to Ghana, the second largest cocoa producer country worldwide, where about 17% of all cocoa areas are affected by CSSVD (Dzahini-Obiatey, personal communication), which poses a great threat for the remaining cocoa areas because of high connectivity of the cocoa landscape, which favors disease spread by mealybug vectors. Around 800,000 farmer families produce Ghana's cocoa (Danso-Abbeam 2014), which means that approximately 5 million people (20% of the population) are directly dependent on cocoa as their most important source of income. Since the only effective treatment for CSSVD is to cut infected trees and replant with disease-free planting material, CSSVD threatens the livelihoods of these people. The Ghanaian government has implemented a national eradication program with the objective to control the disease (Thresh and Owusu 1986). Since its initiation in 1946, the program has been running in an on-and-off manner depending on the political context during the specific periods. In total, more than 300 million trees were cut out (Dzahini-Obiatey, personal communication), which caused immense costs for both the government and the cocoa farmers (Dzahini-Obiatey et al. 2010). When the program was running, farmers were compensated for cutting out and replacing their cocoa. However, when the program was not running, farmers were still encouraged to cut and replace their cocoa, but without any compensation payments, which caused a lot of resistance. Thus, CSSVD is a major issue for all stakeholders in the cocoa value chain of Ghana (Fig. 1).

The Cocoa Research Institute of Ghana (CRIG) has conducted a lot of CSSVD research, a history of which is presented by Andres et al. (2017), and recommended some measure for implementation by the Cocoa Health and Extension Division (CHED), including:

1) Cordon sanitaire (Vanderplank 1947), which involves leaving a 10-m-wide cocoa-free zone around newly planted cocoa, so that mealybug vectors become non-infective when moving into new plantations (because of the semi-persistent nature of the virus in the vector (Posnette and Robertson 1950)). Although this measure was shown to be effective, it also results in loss of income due to less cocoa being planted. Furthermore, when land is left fallow, exposure to direct sunlight may dry out the soil and subject adjacent cocoa trees to increased water stress, and there is a risk that neighboring farmers may claim the fallow portion as part of their farm.
2) Barrier cropping (Domfeh et al. 2016), which involves lining newly planted cocoa orchards with a 10-m barrier of non-host crops, such as citrus, oil palm, coffee, or rubber. Barrier cropping has the advantages of potentially reducing CSSVD infection by up to 85% (Andres et al. 2017), while providing additional income and benefits for household food security and nutrition through diversified production (Domfeh et al. 2016). However, the seeds of barrier crops (especially the ones of oil palm) attract rodents who also feed on cocoa pods, and citrus may attract white flies (see Section 3.1.2). Another disadvantage is the potential loss of income due to lower prices for barrier crops.
3) Planting seedlings of partly tolerant hybrid cocoa varieties (Padi et al. 2013) involves resistance breeding, which can reduce CSSVD infection by up to 30% (Andres et al. 2017). However, high genetic variability of the virus impedes the development of resistant varieties.
4) Removing alternative host trees as recommended by Posnette et al. (1950) involves removing a few specific species of shade trees, which naturally harbor CSSV (e.g., *Cola chlamydanta*, *Ceiba pentandra*, *Adansonia digitata*, *Cola gigantean*, and *Sterculia tragacantha*), thereby

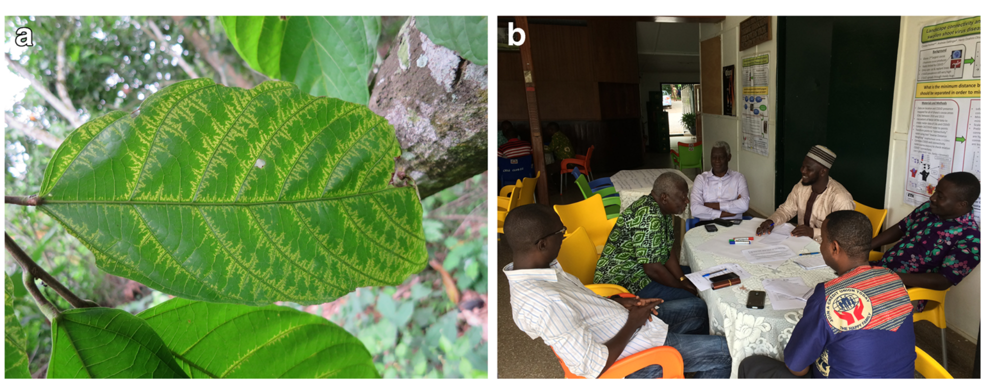

Fig. 1 Left panel: vein clearing, a typical symptom of cocoa swollen shoot virus disease (CSSVD, severe strain 1A) in mature cocoa leaves. Right panel: a group with representatives from all the major stakeholders in the cocoa value chain of Ghana discussing possible solutions to tackle CSSVD. Pictures: author

destroying potential sources of infection and habitats of the mealybug vectors. The disadvantages of this measure are the high costs associated with materials (chainsaws, fuel, etc.) and labor, and that it reduces shade. Andres et al. (2018) showed that shade is vital to reduce the severity of CSSVD symptoms and Smith Dumont et al. (2014) stressed that farmers in Côte d'Ivoire value tree diversity in cocoa for the provision of ecosystem services.

However, the adoption of the recommended prevention measures remains limited and CSSVD is still highly prevalent in Ghana (Ameyaw et al. 2014). The reasons for the reluctance of farmers to implement prevention measures remain largely unknown and there has been little investigation on the barriers to their adoption. Therefore, the aims of this study are to identify both the extent to which these prevention measures have been adopted and the main constraints that prevent cocoa farmers in Ghana from adopting them. To address these aims, we investigated the state of farmers' knowledge about CSSVD in general, and about the prevention measures in particular, and the feasibility of the individual prevention measures for the farmers. Furthermore, we identified the actions that could be taken to increase adoption, and the stakeholders who are most likely to be the drivers of change towards increased adoption of prevention measures.

Many cocoa farmers in Ghana rent their land, cultivating in sharecropping agreements that are often not written down. Both sharecropping agreements and the inheritance system have led to a fragmented cocoa landscape with small farms that are further divided among the family members upon the death of the owner, or between the sharecropper and the landowner (Dzahini-Obiatey et al. 2010). Farmers grow, harvest, ferment and dry the beans before they sell them to the purchasing clerk (PC). The PC is a member of the local community employed by a licensed buying company (LBC) who organizes the purchase and delivery of cocoa to the LBC warehouse. The LBC is responsible for storing and selling the beans to the Cocoa Marketing Company (CMC), which stores, markets and exports the cocoa.

The main actor Ghana Cocoa Board (COCOBOD) dominates the cocoa value chain of Ghana. Established in 1947 as the successor of the Cocoa Marketing Board, COCOBOD facilitates the production, processing, and marketing of good quality cocoa through its various subsidiaries, i.e., CHED, CMC, CRIG, the Seed Production Division (SPD), and the Quality Control Company (QCC). COCOBOD ensures a producer price of more than 50% of the free on board (FOB) prize, and employs around 60,000 people. A reform in 1993 partially liberalized the internal marketing, allowing private LBCs to purchase cocoa from the producers at farm gate (Dormon et al. 2004). Based on this structure of the Ghanaian cocoa value chain, the practices of individual value chain actors mentioned above, as well as a review of the literature and the results of previous research, we hypothesized that the number of farmers who adopt recommended CSSVD prevention measures is significantly higher for farmers:

i) with bigger cocoa farms, as the implementation of barrier cropping, for instance, would claim a smaller percentage of their land than it would for smaller farms;
ii) who know more people (family members or close friends) who have adopted the measures (social network size) because it has been shown that early adopters tend to be those with better information networks (Aguilar-Gallegos et al. 2015);
iii) who had more years of experience in cocoa farming because more experienced farmers are more likely to have received information about prevention measures by extension services;
iv) who had been trained by a voluntary sustainability standard (VSS) certification scheme (e.g., Fairtrade, Rainforest Alliance or UTZ Certified) because VSS teaches farmers about prevention measures and have been shown to trigger behavioral change (Ruben and Zuniga 2011);
v) who have had previous experiences with CSSVD infection because exposure to a production challenge can trigger behavioral change (Brondizio and Moran 2008);
vi) with more knowledge about the measures because knowledge about prevention measures is key to their implementation; and
vii) who are the owners of the land they cultivate (as opposed to sharecroppers) because landowners have higher freedom of action than sharecroppers, since they do not face the fear of job loss when adopting certain measures (Lambrecht and Asare 2015)

2 Materials and methods

2.1 Selection of study sites and participants

We conducted our study in the Eastern and Western Regions of Ghana. These areas have a long history of CSSVD occurrence (Domfeh et al. 2011), and thus many farmers are familiar with the disease and may have considered implementing prevention methods. Furthermore, the regions show biophysical and socio-economic differences: Eastern Ghana has soils that are well suited for cocoa growing, and families mostly own the land. The Western Region has soils that are marginal for cocoa growing and permanent migrants from the northern regions of Ghana mainly grow cocoa in sharecropping agreements. In each region, we selected two operational districts of

CHED: Oyoko (high CSSVD prevalence) and Nkawkaw (low CSSVD prevalence) in the East, as well as Buaku (high CSSVD prevalence) and Sefwi Bekwai (low CSSVD prevalence) in the West (Fig. 2).

CHED assisted us in the selection of farmers for the survey and focus group discussions. Since we relied on their recommendations and had to consider logistical aspects (i.e., accessibility), our selection method was not random. However, we ensured representativeness by selecting communities based on spatial data at community level about the prevalence of CSSVD (high/low), certification (high/low number of certified farmers) and farm size (average farm size </> 3 acres), before selecting individual farmers in the communities.

The median values characterizing the participating farmers were the following: 50 years old, living in a household with seven members, had been cultivating cocoa for 15 years, and had two cocoa plantations of about 1.2 ha each. About a quarter of the farmers were women, and two thirds were landowners, while one third were sharecroppers. Our sample is in line with those by Hainmueller et al. (2011) and Muilerman (2013), who reported the median values of the following: farmer age (50), household size (5 and 6 in Hainmueller et al. (2011) and Muilerman (2013), respectively), number of farms per farmer (2), farm size (1.2 ha), proportion of women farmers (19%), and proportion of landowners (70%). Forty-three percent of the participating farmers produced cocoa certified by one VSS such as Fairtrade, Rainforest Alliance or UTZ certified, which is considerably higher than the 15% reported by Deppeler (2014). Those VSS generally do not provide support for tackling CSSVD, except for some UTZ certified farmers, who mentioned that they received such support.

2.2 Data collection

2.2.1 Farmer survey

Between January and March 2017, we performed a face to face quantitative survey with 396 farmers in the four CHED operational districts mentioned above (see Section 2.1), using a questionnaire with 18 closed single-choice and three open-ended questions, which we had pre-tested and adapted in collaboration with experts from the Research Institute of Organic Agriculture (FiBL). While the closed questions were aimed at investigating the factors that might hinder the adoption of recommended CSSVD prevention measures, the open questions were aimed at getting a better understanding of the state of farmers' knowledge about CSSVD in general and about the prevention measures in particular. Responses were recorded directly on pre-programmed tablet computers. With the help of CHED facilitators, we conducted all interviews in the local

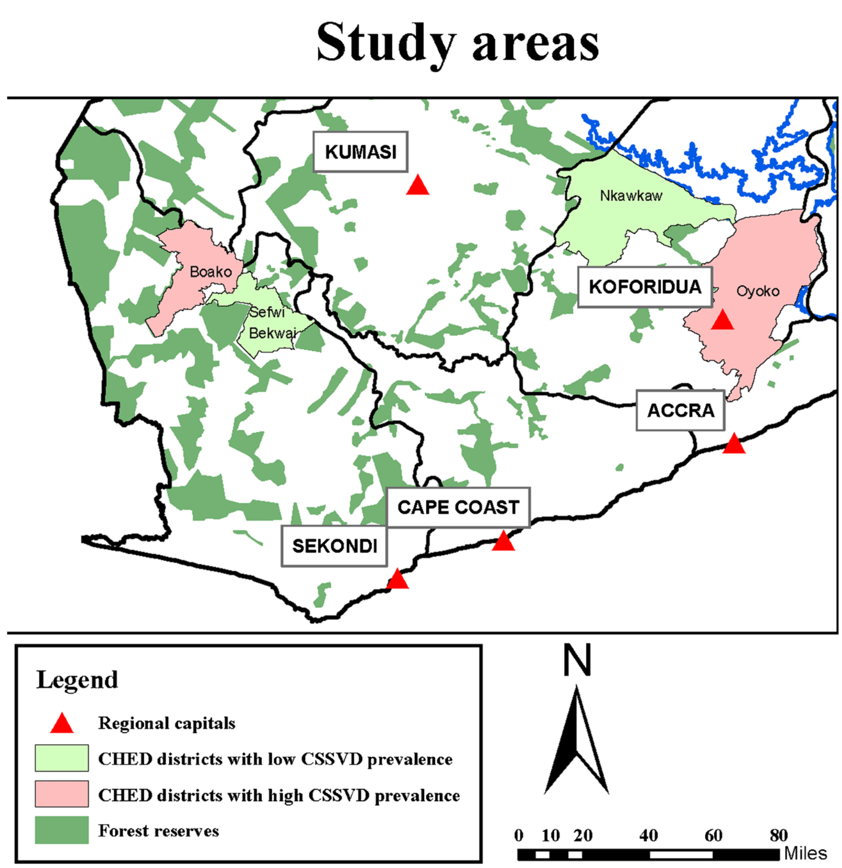

Fig. 2 Study areas in operational districts of the Cocoa Health and Extension Division (CHED) in the Eastern and Western regions of Ghana: Oyoko (high prevalence of cocoa swollen shoot virus disease (CSSVD)) and Nkawkaw (low CSSVD prevalence) in the East, Buaku (high CSSVD prevalence) and Sefwi Bekwai (low CSSVD prevalence) in the West

language (Twi) and attempted to create a common baseline knowledge among all the participants by providing information about the virus, its symptoms, and prevention measures using illustrated information leaflets. The information leaflet was provided after initial questions on farmers' knowledge of the prevention measures had been asked, and before we had a more detailed discussion on the individual prevention measures.

We collected data about age, gender, household size, total acreage of cocoa farms and number of fields, social network size, number of years in cocoa farming, certification (binary, yes/no), experience with CSSVD infection (binary, yes/no), knowledge about prevention measures (binary, no/some knowledge), and land tenure (binary, landowner/sharecropper). Regarding the variable knowledge, we coded it 1 (some knowledge) if a farmer was able to mention a prevention measure, whereas we coded it 0 (no knowledge) if a farmer mentioned any other measure (e.g., cutting trees as a treatment for CSSVD infections) or nothing at all. We obtained the acreage per field by dividing the total acreage of each cocoa farm by the number of fields. The social network size was defined as the number of family members or close friends who had already adopted a particular prevention measure. We assessed adoption of CSSVD prevention measures by asking farmers whether they knew the measures, and, if yes, whether they had tried them before, or were still practicing them.

2.2.2 Focus group discussions and transdisciplinary multi-stakeholder workshop

With the goal to complement the farmer survey, we performed six semi-structured focus group discussions, between January and March 2017, using a questionnaire with main, additional, and clarifying questions as proposed by Laforest (2009). The questions were pre-tested and adapted in the same way as described above (see Section 2.2.1). To facilitate free talking, we selected farmers who belonged to the same farmer group or originated from the same community. The focus groups consisted of eight to 11 farmers. Again, we conducted all the discussions in the local language (Twi) with the help of local moderators.

With the aim to validate the results from the farmer survey and the focus group discussions, we conducted a workshop with representatives of the major stakeholders in the cocoa value chain of Ghana in April 2017. A total of 31 people representing the six major stakeholders: (i) CHED extension agents, (ii) Ghana Cocoa Board (COCOBOD) managers, (iii) CRIG scientists, (iv) farmers, (v) LBC representatives, and (vi) non-governmental organization (NGO) representatives, participated in the workshop. Through interactive exercises and discussions, participants elaborated stakeholder-specific needs and challenges concerning CSSVD. Furthermore, participants discussed the necessary future steps towards effective implementation of the most promising potential solutions, and gave opinions about the responsibility of individual stakeholders to take these steps.

2.3 Data analysis

Qualitative data from the open-ended questions in the farmer survey, the focus group discussions, and the multi-stakeholder validation workshop were translated into English, and analyzed for common themes or categories using the guidelines by Eliot and Associates (2005). The identified themes were then used to confirm or support the interpretations of the quantitative results from the farmer survey.

To analyze our quantitative data, we used binary logistic regression models for each of the four prevention measures (dependent variables) to identify any significant effects on the adoption of CSSVD prevention measures. To decide which explanatory variables to include in the logistic regression analyses, we started from the model with all explanatory variables and two-way interactions, and removed non-significant interaction terms as well as separate variables from the model if they did not improve the model fit (or pseudo R^2) significantly. This led to four measure-specific models (Table 1), which together included the continuous variables: (i) "acreage per field," (ii) "social network size," (iii) "number of years in cocoa farming," and categorical (binary) variables: (iv) "certification," (v) "experience with CSSVD infection," (vi) "knowledge," and (vii) "land tenure," as well as some influential two-way interactions of these explanatory variables. In addition, we included the variables "age," "gender," and "district" in all four measure-specific models to account for confounding effects.

We used the Wald chi-square statistic (Wald χ^2) to test the statistical significance of individual regression parameters. To assure that the model assumptions for binary logistic regression were not violated, we checked for linear relationships (linearity of logit) using the model fit statistic and R^2 values. We also checked for multicollinearity by verifying correlations among explanatory variables with the help of a correlation matrix. As none of the variables showed correlations of $r \geq 0.8$, multicollinearity was considered to be negligible in our dataset, which was confirmed by the finding that no variable had a greater variance inflation factor than 2.5 (Allison 2012).

When testing several hypotheses with one model, correction for multiple testing is necessary to minimize the likelihood of type 1 error accumulation (rejecting the null hypothesis when it is actually true). However, since the number of hypotheses we tested together was relatively small (five to six), we used the Bonferroni-Holm method to account for multiple testing, which is slightly less conservative than the Bonferroni correction (Abdi 2010). We performed all statistical analyses with the statistics software IBM SPSS Statistics, Version 23.

Table 1 Model results from binary logistic regression analyses about the adoption of the four CSSVD prevention measures

Variables (dependent/explanatory)	B	sem	Wald χ^2	*P* value	Exp(B)	95% CI for Exp(B)	
						Lower	Upper
Adoption cordon sanitaire							
Social network size	4.517	1.420	10.112	.018*	91.524	0.001	0.177
Knowledge	3.780	1.300	8.451	.040*	43.802	0.002	0.292
Social network size × number of years in cocoa farming	0.102	0.051	3.942	.047*	0.903	1.001	1.224
Adoption barrier cropping							
Knowledge	3.397	0.836	16.511	.001**	30.303	0.007	0.172
Social network size	1.955	0.480	16.618	.001**	7.042	0.055	0.362
Acreage per field	0.528	0.167	10.023	.020*	1.695	1.223	2.350
Land tenure	3.176	1.047	9.206	.029*	23.961	3.079	186.465
Acreage per field × land tenure	− 0.484	0.176	7.574	.006*	0.617	0.437	0.870
Adoption hybrid seedlings							
Acreage per field × experience with CSSVD infection	0.324	0.116	7.761	.005*	1.382	1.101	1.735
Certification × social network size	− 0.092	0.033	7.836	.005*	0.913	0.856	0.973
Adoption alternative host tree removal							
Social network size	0.046	0.017	7.142	.023*	1.047	1.012	1.084
Gender	2.512	1.068	5.535	.037*	12.334	1.521	100.030
Gender × land tenure	− 2.943	1.113	6.994	.008*	0.053	0.006	0.467
Acreage per field × certification	− 0.248	0.116	4.587	.032*	0.781	0.622	0.979

B, parameter estimate; *sem*, standard error of the mean; *Wald* χ^2, Wald chi-square statistic; *Exp(B)*, odds ratio; *CI*, confidence interval; *, **significant at $P < 0.05$, < 0.01, respectively (after Bonferroni-Holm correction)

Odds are defined as the likelihood of an event occurring versus the likelihood of the event not occurring. It can be expressed with the following formula: odds = $p/(1\text{-}p)$. Of particular interest are the odds to achieve a certain outcome conditional on a variable (e.g. gender). As an example for gender, after the odds to achieve an event for males and females have been calculated, the division of these odds creates the odds ratio. This ratio states how much more likely it is for males (or females) to achieve a certain outcome compared to females (or males).

The results were interpreted in light of the technology acceptance model (TAM) (Davis 1989) as a theoretical framework to study and interpret farmers' behavior in the adoption of recommended CSSVD prevention measures. TAM proposes that "perceived ease of use" and "perceived usefulness" combined, create an intention and lead to behavior. In practical terms, this means whether people have the skills to use recommended CSSVD prevention measures, and whether they perceive their use to be of benefit to them. In our study, however, behavior is further influenced by whether people have access to recommended CSSVD prevention measures, so we adapted TAM by including the factor "perceived access," which, in this case, implies knowledge of the prevention measure. Thus, the theoretical framework guiding our study is based on the assumption that perceived access, perceived ease of use, and perceived usefulness combined, create an intention and lead to behavior.

3 Results and discussion

3.1 Adoption of the four CSSVD prevention measures

The adoption of any of the four CSSVD prevention measures was most significantly influenced by the factors "social network size," "acreage per field," "land tenure," "knowledge," "certification," "experience" (includes factors "number of years in cocoa farming" and "experience with CSSVD infection"), and "gender." These factors, or their interaction with another one of these factors, had significant effects on the adoption of any of the four CSSVD prevention measures in 5, 4, 2, 2, 2, 2 (1 and 1), and 2 cases, respectively (Fig. 3).

The model results from binary logistic regression analyses about the adoption of the four CSSVD prevention measures are shown in Table 1. Of particular interest is column Exp(B) (odds ratio), which states—in the case of gender, for example—how much more likely it is for males (or females) to adopt a particular prevention measure. To calculate the odds ratio for the interaction terms, the parameter estimate (B) and

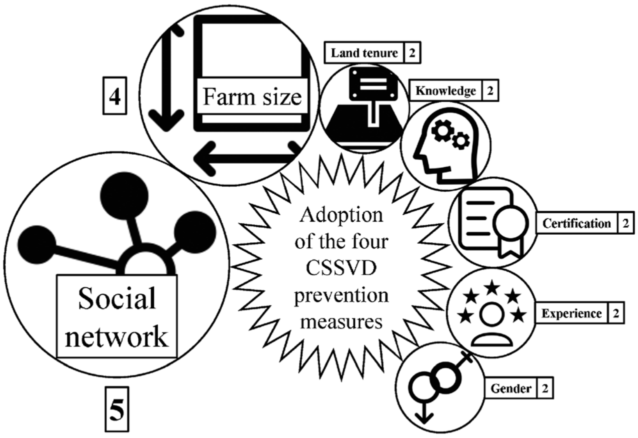

Fig. 3 Most significantly influencing factors on the adoption of any of the four cocoa swollen shoot virus disease (CSSVD) prevention measures. The size of the circle is proportional to the number of cases in which the respective factors had a significant effect on the adoption of any of the four CSSVD prevention measures

standard error of the mean (sem) are needed; therefore, they are included in Table 1. Furthermore, it is important to know the reference category from which the odds ratio is calculated for all categorical variables. These are "no knowledge" (knowledge), "small social network" (social network), "sharecropper" (land tenure), "some infection" (CSSVD infection), "certified" (certification), and "female" (gender).

The percentages of surveyed farmers who had already adopted prevention measures were 9% for cordon sanitaire, 12% for barrier cropping, 41% for hybrid seedlings, and 40% for alternative host tree removal. In reality, however, the adoption rates may be even lower because hybrid seedling and alternative host tree removal are associated with other perceived benefits, and thus may not have been adopted to prevent CSSVD.

The prevention measures "hybrid seedlings" and "alternative host tree removal" have a high adoption potential because farmers perceived them to be useful. However, barriers to adoption were found to be difficulties in accessing the hybrid seedlings, and that removal of alternative host trees is not perceived to be easy. Farmers perceived cordon sanitaire and barrier cropping to be less useful, which highlights the need for education campaigns to stress the effectiveness of these prevention measures (Vanderplank 1947; Domfeh et al. 2016). The participating farmers consistently mentioned the need for technical advice and access to hybrid seedlings as challenges, which participants of the validation workshop also stressed to be of vital importance for potential solutions to prevent CSSVD.

3.1.1 Cordon sanitaire

"Social network size," "knowledge," and the interaction between "social network size" and "number of years in cocoa farming" had significant effects on the adoption of cordon sanitaire (Table 1). The results suggest that being relatively new to cocoa farming combined with having a social network of two or more who had already adopted cordon sanitaire were associated with more adoption of this prevention measure. This may be explained by the responses to the open-ended questions in the interviews, which indicated that cocoa farming, in general, is a traditional livelihood activity of local families, where children learn about farming practice from their parents. Farmers with more than 15 years of experience may have firmly established habits in their practice, and may therefore be reluctant to accept and adopt new recommendations that are unfamiliar to them, such as leaving a cordon sanitaire around the entire farm. Similarly, farmers with some knowledge about cordon sanitaire were much more likely to adopt the measure than farmers without any knowledge (Table 1).

When asked about their challenges, farmers stated that cordon sanitaire is not feasible because it would lead to water stress for adjacent cocoa trees, higher weed pressure, and thus labor requirements, and that neighboring farmers might claim the fallow land for themselves. Thus, although farmers may have been convinced of the usefulness of cordon sanitaire, many perceived it to be difficult to implement, which violates a requirement of the technology acceptance model (Davis 1989). Of the farmers who mentioned specific challenges with cordon sanitaire, 62% said that their farm is too small to implement this preventive measure.

3.1.2 Barrier cropping

"Knowledge," "social network size," "acreage per field," "land tenure," and the interaction between "acreage per field" and "land tenure" had significant effects on the adoption of barrier cropping (Table 1). Similar to the results for cordon sanitaire, the two strongest predictors for adoption were "knowledge" and "social network size." With a median farm size of about 1.2 ha, implementing barrier cropping may claim up to 30% of the land, which may be another explanatory factor for the limited adoption. Furthermore, potential revenues from barrier crops may not fully compensate for reduced cocoa yields (Ameyaw et al. 2014), so there is a need for more in depth evaluation of the economic potential of different barrier crops (Domfeh et al. 2016).

Our results suggest that landowners were more likely to adopt barrier cropping than sharecroppers were, but adoption increased significantly when the farm size was larger than 1.2 ha, especially among sharecroppers. While this result suggests that landowners may be more open to considering requests from their sharecroppers with larger farm sizes, it also points to the limited freedom of action for sharecroppers, which is associated with the fear of job loss when adopting measures such as cutting out infected cocoa trees (Lambrecht and Asare 2015). Focus group participants confirmed the threat of landowners taking back their land if they suggested implementing barrier cropping after cutting down infected cocoa. Thus, the root cause of the problem may yet again be a lack of knowledge, but on the side of the landowners. As long as the landowners are not convinced of the usefulness of barrier cropping (due to a lack of knowledge), the adoption of barrier cropping will be minimal. Thus, this violates the "perceived usefulness" requirement of the technology acceptance model (Davis 1989). Educating landowners about CSSVD may help them to make informed decisions about future land use together with their sharecroppers, and thereby remove this barrier to adoption.

When asked about the challenges of adopting barrier cropping, farmers mentioned access to barrier crop seedlings as the most important issue. Furthermore, barrier crops may compete with cocoa for light and water, which may favor diseases such as black pod (*Phytophthora* spp.), and they can attract pests such as rodents (oil palm) or white flies (citrus).

3.1.3 Hybrid seedlings

The two interactions between "acreage per field" and "experience with CSSVD infection," as well as between "certification" and "social network size" had significant effects on the adoption of hybrid seedlings (Table 1). Farmers who had individual farms of more than 1.2 ha in size were less likely to use hybrid seedlings when their farm was infected by CSSVD. This may be explained by the greater financial resources needed to replant bigger farms with hybrids compared to smaller farms, and by the limited availability of hybrid planting materials in large numbers. Moreover, farmers with a larger social network who already adopted hybrid seedlings, and especially those who had been trained by a VSS certification scheme, showed higher adoption rates compared to farmers with a smaller social network. This may be due to larger social networks of certified farmers being more efficient in spreading knowledge about hybrids. We therefore encourage organizations that are active in certification to exchange up to date information with extension services to profit from each other's experiences.

When asked about their main challenges, the majority of farmers (60%) stated access to hybrid seedlings and associated transport costs, as well as timely delivery of seedlings (i.e., during the rainy season), which was especially the case for farmers living in remote villages. Thus, the primary barrier to adoption of this prevention measure appears to be related to access to the technology (seedlings) (Davis 1989).

3.1.4 Alternative host tree removal

"Social network size" and "gender," as well as the two interactions between "gender" and "land tenure," and between "acreage per field" and "certification" had significant effects on the adoption of alternative host tree removal (Table 1). The strongest predictor indicated that farmers with a larger social network were more likely to remove alternative host trees.

Our results suggest that for farms larger than 1.2 ha in size, farmers who had been trained by a VSS certification scheme were more likely to remove alternative host trees compared to non-certified farmers. This may be due to certification agents educating farmers about alternative host trees. The increased adoption on larger farms may be explained by farmers disposing of more financial resources, which enabled them to fell the trees or simply by a higher frequency of alternative host trees on larger surfaces. While the adoption rates of prevention measures did not differ between male and female landowners, male sharecroppers removed alternative host trees significantly more often than their female counterparts did. This indicates that less secure land tenure imposes more insecurities for women than for men, which affects their willingness to risk adopting alternative host tree removal. An alternative explanation is that women sharecroppers may simply have access to fewer resources than men have, or lack the necessary physical force to fell alternative host trees by themselves.

When asked about their challenges, farmers mentioned the damage caused by felling shade trees, the need to provide shade for cocoa trees and the associated costs for machines and labor to remove the trees. The primary barrier to adoption of this prevention measure appears to be the difficulties (and costs) in implementing the prevention measure, which the technology acceptance model would describe as an issue of "perceived ease of use," although the "perceived usefulness" (Davis 1989) appears to be also diminished by the prevention measure producing another problem that needs to be solved.

3.2 General needs and challenges of different stakeholders, and proposed solutions

Different stakeholders expressed contrasting views on how to tackle CSSVD. While farmers stressed that lack of information and education presented the biggest challenge to preventing CSSVD, and frequent training workshops were therefore their greatest need, other stakeholders mainly stressed that they are facing resource constraints, especially funding, to address the CSSVD challenge by increasing collaboration and reaching out more frequently to farmers. Furthermore, participants of the validation workshop mentioned improving information flow, existing policies and land tenure systems as key issues to tackle the CSSVD problem.

The participants of the validation workshop agreed that more collaboration and participation among stakeholders is needed in aspects such as research, information sharing, quality assurance and policymaking. They suggested that increased collaboration would facilitate information exchange while also building mutual respect and trust, and may be achieved through the establishment of demonstration farms across the cocoa growing regions of Ghana by collaborative efforts of COCOBOD, NGOs, LBCs and farmers. It would be especially important to involve the traditional leaders (chiefs) in those platforms, as they are important local decision-makers; by reigning over the land, they directly influence future areas of cocoa growing. Furthermore, anyone who wishes to grow cocoa, and who is not a landowner or sharecropper of someone who had acquired a piece of land before the constitutional change in 1992 (which forbid selling land to individuals in Ghana), has to pass through the chief to negotiate a land deal. Therefore, the chiefs are crucial to ensure that the word will spread to the farmers who are affected by CSSVD. If the chiefs had the appropriate knowledge, as well as all the necessary information, they could even influence the connectivity of the cocoa landscape in order to minimize disease spread.

Furthermore, the chiefs are key actors when it comes to the revision of Ghana's land tenure system. The current system has led to small farm sizes, as inheritance and sharecropping practices continue to fragment the cocoa landscape into ever-smaller cocoa farms (Dzahini-Obiatey et al. 2010). This is not only problematic for the rehabilitation of farms destroyed by CSSVD, but it also impedes the adoption of cordon sanitaire and/or barrier cropping. To effectively increase farm size, the proposition to set up land banks into which individuals, families and other landowners could be encouraged to pledge their lands to be used for specific projects, which may include rehabilitation of farms destroyed by CSSV as proposed by Dzahini-Obiatey et al. (2006) should be revisited by the central government.

3.3 Knowledge and information flow

Lack of knowledge about CSSVD prevention measures was the single biggest barrier for their adoption, with 51% of all the participating farmers not even being aware of them. Lack of awareness means that the prevention measures are not accessible to farmers, thus a requirement of the technology acceptance model is not fulfilled (Davis 1989). Prior to showing the farmers the information leaflets, only 12% mentioned that they knew at least one of the four prevention measures. Farmers who had been shown the leaflets reported knowledge of cordon sanitaire (37%), barrier cropping (41%), use of hybrid seedlings (69%), and alternative host tree removal (71%). This shift indicates a significant lack of knowledge in that most farmers were not aware of the measures being at least partly effective in CSSVD prevention, even when many farmers knew about them. The lack of knowledge was also reported in the focus group discussions and the multi-stakeholder workshop.

Furthermore, the results suggest that the social network has the most potential as a source of information about CSSVD prevention measures that may lead farmers to adopt them. However, the median values of social network size was 0 people for cordon sanitaire, 0 for barrier cropping, six for hybrid seedlings, and five for alternative host tree removal, indicating that more than half of the farmers did not know anyone who had already adopted cordon sanitaire or barrier cropping. A limitation of our study was that we were unable to check the accuracy of information spread by social networks. Furthermore, we were not able to conduct follow-up interviews with participating farmers to confirm our interpretation of their responses. These remain topics for future research.

Baah (2008) showed that the media (radio, TV) was the preferred information source of farmers, with extension agents and social networks ranking second and third. Thus, CSSVD-specific radio programs could be a potential solution to addressing the identified lack of knowledge about prevention measures. Specific videos that could be transmitted via television or shared among farmers via Bluetooth on 3G mobile phones, a technology whose potential has been demonstrated for West Africa (Sousa et al. 2016), may also enable transfer of knowledge about the prevention measures. Furthermore, the focus group discussions revealed that farmers would like to be visited more frequently by extension agents but the high farmer to extension agent ratio of 2,500/1 challenges CHED to physically reach out to farmers, which underlines the reported inadequacy of extension support for Ghanaian cocoa farmers (Baah 2008). The participants of the validation workshop collectively stated the opinion that this ratio should be lowered to at least 500/1.

The current knowledge on the barriers to the adoption of CSSVD prevention measures for farmers is very limited. Here, our study offers novel insights, showing that more than half of the participating farmers were not even aware of what they can do to prevent CSSVD. Insufficient knowledge spread is the key constraint to overcome in order to increase limited adoption. Based on our data, we suggest capitalizing on farmers' social networks to enhance information flow in order to achieve this. Furthermore, the revision of Ghana's land tenure system (see Section 3.2) is imperative to address the issues of small farm sizes and insecure land tenure rights, both of which are hindrances to increasing the adoption of CSSVD prevention measures, as well as any potential land accumulations. With this study, a first step has been taken towards a potential action plan that enhances the adoption of CSSVD prevention measures in Ghana to remediate the CSSVD menace efficiently.

4 Conclusions

Here, we identified significant barriers to the adoption of the four CSSVD prevention measures: (i) cordon sanitaire, (ii) barrier cropping, (iii) using partly tolerant hybrid planting material, and (iv) removing alternative host trees by cocoa farmers in the Eastern and Western Regions of Ghana. In general, we found a severe lack of knowledge, and hence low adoption rates, among the participating farmers with respect to CSSVD and prevention measures. Farmers with wider social networks, larger farms, more knowledge, and those who were landowners were more likely to adopt the measures than farmers with smaller social networks and farms, less knowledge, and being sharecroppers. Furthermore, farmers with fewer years of experience in cocoa farming, along with those who had previous experience with CSSVD infection showed higher adoption rates.

This is the first time these four CSSVD prevention measures were evaluated in light of the technology acceptance model (Davis 1989). All of them partly satisfied the prerequisites of the model, and we found that access in the form of awareness was the most important factor influencing adoption. Given that a combination of locally adapted prevention measures may provide the best defense against CSSVD, complex information has to be conveyed to smallholders in an understandable way. Validation workshop participants stressed the development of a new extension manual for sustainable cocoa production to be of vital importance in this respect. While such a manual may not be the primary solution for farmers, it may help ensuring a uniform state of knowledge among extension agents, the contents of which would subsequently need to be adequately translated using illustrations and simple, non-technical language, and transferred to farmers in frequent workshops.

Since the information flow among stakeholders in the cocoa value chain of Ghana is a key factor affecting knowledge spread and thus the adoption of CSSVD prevention measures, future research should explore knowledge transfer methods that capitalize on social networks as a key vehicle to increase the effectiveness of extension services and thus technology adoption. It is especially important to involve the traditional leaders (chiefs) in such knowledge transfer methods to ensure that the word will spread to the farmers who are affected by CSSVD. We recommend providing agricultural information to Ghanaian cocoa farmers through a dissemination strategy based around radio programs and videos on TV and mobile devices to complement direct interactions between farmers and extension agents.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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