Effects of biotic and abiotic stress on household cocoa yields in Ghana

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Abstract

Few empirical studies have estimated the direct effects of biotic (disease and pest) and abiotic (e.g. drought and flood) stresses on cocoa-producing households. As such, this study extends the existing literature by using household-level data from Ghana over three cocoa growing seasons (2002, 2004 and 2006) in a regression framework to estimate the responsiveness of cocoa yields to biotic and abiotic stress at the household level. The results show that, for farms exposed per year, overall stress from pests makes up the highest percentage, followed by disease stresses and abiotic stresses. In addition, the results from the regression model show that cocoa yields decline by 0.046%, 0.013% and 0.003% respectively for every one percent increase in the proportion of the farm affected by disease, pests and abiotic stress that persist for a year. The findings of this study suggest that the government of Ghana should consider expanding the scope of the National Cocoa Diseases and Pest Control Programme to include other pests that are not included in the programme. We also recommend an insurance product for cocoa to help farmers manage the risks of abiotic stresses such as droughts and floods that destroy investments and potential income.

Key words: cocoa; disease; pest; abiotic; stress; Ghana

1. Introduction

Since the introduction of cocoa (*Theobroma cacao*) in Ghana in the 1880s, the crop has transformed the country's agriculture sector and continues to play a significant role in the socio-economic development of the country. Cocoa production accounts for approximately 55% of the total income of cocoa-producing households (Ghana Statistical Service [GSS] 2008). In addition, as one of Ghana's principal export commodities, cocoa accounts for 3.2% of GDP and 12% of agriculture GDP (Ministry of Food and Agriculture [MOFA] 2013). Globally, Ghana accounts for 24% of total world cocoa exports, making it the world's second-largest cocoa producer (International Cocoa Organization [ICCO] 2012). Nevertheless, Ghana's cocoa production and supply chain are plagued with issues such as (1) biotic and abiotic stress (pests/disease, dry spells and bushfires), (2) market risks (price volatility, input price volatility, exchange rate volatility and interest rate volatility), and (3) enabling environment risks (cocoa smuggling, market regulation risk, policy risk, logistics breakdown and misappropriation of funds) (World Bank 2013). Among these issues, biotic and abiotic stresses pose the greatest risk to Ghana's cocoa supply chain (World Bank 2013). Notably, these risks may be amplified if climatic variations increase due to climate change.

In comparison to the major cocoa-producing countries in Sub-Saharan Africa (Cote d'Ivoire, Ghana, Nigeria and Cameroon), Ghana's cocoa production has experienced the most dramatic biotic stresses in terms of frequency and total loss. Particularly, there have been multiple eradication campaigns through the National Cocoa Diseases and Pest Control (CODAPEC) programme, popularly known as "mass spraying", to control cocoa swollen-shoot virus (CSSV) and black pod fungus. Ghana's eradication campaigns, particularly for CSSV, are considered the most ambitious and expensive campaigns for the control of a plant viral disease anywhere in the world (Thresh *et al*. 1988; Dzahini-Obiatey *et al*. 2006; 2010). The latest estimates show that over 200 million trees are lost to CSSV annually in Ghana (Ollennu *et al*. 1989; 2007; Dzahini-Obiatey *et al*. 2010), which results in revenue loss for producers, food insecurity increases via deteriorating purchasing power, and revenue loss from government tax. Given that cocoa accounts for 55% of the total income of cocoa-producing households, any loss has extreme implications for individual households, since entire orchards may be destroyed, thereby disrupting or eliminating their livelihoods.

While several studies have estimated the impacts of biotic stress on cocoa production at the national and global level (Blencowe & Wharton 1960; Akrofi *et al*. 2003; Ndoumbe-Nkeng *et al*. 2004; Guest 2007; Deberdt *et al*. 2008), only a few have studied the impact of biotic stress on cocoa production at the household level. Furthermore, no study has evaluated the impact of abiotic stress, in part because of a lack of extensive cocoa datasets. The most recent estimates, by Aneani and Ofori-Frimpong (2013), used ordinary least squares (OLS) on a cross-sectional survey sample of 300 cocoa farmers in Ghana to show that the frequency of spraying fungicides against capsids increased cocoa yields by 24.01 kg/ha. Conversely, their model also indicated that the frequency of spraying against black pod decreased cocoa yields by 22.02 kg/ha. Aneani and Ofori-Frimpong (2013) attributed the negative relationship between black pod control and yield to be a result of the improper and inefficient application of fungicides and the difficulty involved in spraying, which leads to poor control of black pod disease. In another study in Ghana, Ndoumbe-Nkeng *et al.* (2004) showed that the removal of black pod-diseased pods reduced the infestation rate by nine to 31% in the first year, and nine to 11% in the second year, using data collected from field experiments carried out on two separately treated plots (without and with the removal of cocoa black pod-diseased pods) and over two successive years. Notably, their results indicated that, although production was higher in the plots with the removal of infected pods, the difference between the two treatments was not significant.

With these studies in mind, our study extends the existing literature by using household-level data from Ghana over three cocoa-growing seasons (2001/2002, 2003/2004 and 2005/2006) in an OLS regression model framework to estimate the responsiveness of cocoa yields at the household level to biotic stresses (diseases (virus and fungus) and pests (insects, rodents and parasites)) and abiotic stresses (drought and flood). The major contribution of our work hinges on the fact that we used the coverage and persistence of the biotic and abiotic stresses to construct a single stress indicator and then employed that in the regression. With this measure we were able to estimate the yield effect of a given proportion of a cocoa farm exposed to these stresses that persist for a year.

2. Materials and methods

2.1 Specification of regression model

To estimate the direct impact of biotic and abiotic stress on cocoa productivity, a regression model was specified and estimated by OLS. The outcome variable was taken as the natural log of the cocoa yield, measured in kg/ha (Y_{it}) for the h^{th} household in period t. The model is:

$$Y_{ht}=\beta_0 + \boldsymbol{\beta}_1\mathbf{S}^{i}_{ht} + \boldsymbol{\beta}_2\mathbf{S}^{ij}_{ht} + \boldsymbol{\beta}_3\mathbf{F}_{ht} + \boldsymbol{\beta}_4\mathbf{I}_{ht} + \boldsymbol{\beta}_5\mathbf{E}_{ht} + \boldsymbol{\beta}_6\mathbf{H}_{ht} + \boldsymbol{\beta}_7\mathbf{G}_{ht} + \boldsymbol{\beta}_8\mathbf{L}_{ht} + \boldsymbol{\beta}_9\mathbf{LS}_{ht} + \varepsilon_{ht} \quad (1)$$

where the vector $\mathbf{S}^{i}_{ht}$ contains the biotic and abiotic stress variables, and $\mathbf{S}^{ij}_{ht}$ contains the interaction term between the i^{th} and j^{th} stress variable. In constructing the biotic and abiotic stress variables, unexpected events faced by households were grouped into three broad categories: diseases, pests and abiotic events. All fungal and viral events, e.g. swollen shoot, black pod, mushroom/fungus, etc., were categorised as diseases; all insect, rodent and parasite-related events, e.g. grass cutter, termites, mistletoe, etc., were categorised as pests; and all non-biological events, e.g. drought, floods, etc., were categorised as abiotic events. For each of these events, farmers stated the coverage and persistence. Coverage was described as the proportion, in percentage (%), of the total number of farms affected by the event, and the persistence was described as the number of months the event lasted. The persistence was subsequently annualised by dividing by 12. Note that it is possible to observe multiple events for a given farmer. As such, the coverage and persistence for the three categories were taken as the maximum for the events represented in that category. To demonstrate, if farmer "A" reports the incidence of three pest events, such as grass cutter, termites and mistletoe, in year "T", with their respective coverages reported as 10%, 12% and 50%, and persistence is reported as three months, two months and one month, then the coverage and persistence of a pest event for farmer "A" in year "T" would be taken as 50% and three months respectively. Subsequently, the stress variable for each category was calculated as the product of the respective percent coverage and persistence, and thus the interaction term for coverage and persistence. The coefficient represented in $\boldsymbol{\beta}_1$ can be taken as the marginal effect of a percentage of the farm that is affected by the i^{th} stress event (disease, pest or abiotic) that persists for a year. The reason for this interpretation is that the interaction term for coverage and persistence takes on the value of unity if, and only if, coverage is equal to one percent and persistence is one year.

The vectors $\boldsymbol{F}$, $\boldsymbol{I}$, $\boldsymbol{E}$, $\boldsymbol{H}$, $\boldsymbol{G}$ and $\boldsymbol{L}$ contain variables for each respective cocoa farm characteristic: production, input usage, production equipment and assets, household characteristics, growing season, and location fixed effects. The vector $\boldsymbol{LS}$ is the interaction term for location ($\boldsymbol{L}$) and the stress variables ($\boldsymbol{S}$). The variable ε_{it} is the error term with mean zero and was assumed to be distributed independently of diseases, pests and abiotic stress events. Because each farmer in the sample can be observed multiple times, robust standard errors were estimated that recognise the clustering for a given farmer; these are also robust for heteroscedasticity. Furthermore, the null hypotheses of interest in Equation 1 is that diseases, pests and abiotic stress events have no significant effect on cocoa yield, thus $e_i = 0$, where e_i is the partial elasticity of Equation 1 with respect to the i^{th} stress variable. Given that the log-linear nature of the outcome variable, i.e. the natural log of the cocoa yield, the biotic and abiotic stress elasticities on cocoa yield can be estimated as:

$$e_i = (\partial Y_{it}/\partial L_i)(\bar{S}_i/\bar{Y}_{it}) = \delta_{1i} \times \bar{S}_i \quad (2)$$

where δ_1 is a vector containing the partial derivative of Equation 1 with respect to the i^{th} stress variable and evaluated at the sample means of all the covariates in Equation 1. In addition, since the dependent variable is taken as the natural log for all independent variables that are either binary or categorical, the independent variable coefficients ($\widehat{\boldsymbol{\beta}}_j$) can readily be converted into estimates of the percentage yield change ($\widehat{\boldsymbol{\beta}}^*_j$) attributable to these variables, by computing:

$$\widehat{\boldsymbol{\beta}}^*_j = \left(e^{\widehat{\boldsymbol{\beta}}_j} - 1\right)100\% \quad (3)$$

However, independent variables that are continuous (farm size, labour, fertiliser, insecticide, fungicide, household size and education of household head) enter the model in log form, so their coefficients are interpreted as elasticities.

2.2 Data

The household-level data used for the econometric analysis was derived from the Ghana Cocoa Farmers Surveys (GCFS). The first round of sampling was conducted in 2002 (GCFS1), with follow-up surveys conducted in 2004 (GCFS2) and 2006 (GCFS3), culminating in a three-year panel dataset. The GCFS1 sample consists of 492 randomly selected households from 25 villages across the cocoa-growing region of Ghana. The villages were selected with probabilities proportional to the size of the cocoa-farming population in each village. The sampling unit within a given village was taken as the farmer and not the household, in order to observe multiple farmers in a single household. For the second round (GCFS2), farmers who had moved away from the location site were replaced by the new primary owners of the land. Where this failed, additional households were sampled. A similar strategy was used for the GCFS3 in 2006. The datasets are available for public use at Zeitlin (2015); for more details and information on the sampling technique and data collection, CSAE & COCOBOD (2006) describe these aspects fully.

After merging the three surveys, the sample used in this study was composed of 1 353 households. The summary statistics of selected variables for the panel sample used in this study are shown in Table 1. The table indicates that 16% of the heads of household are female and consist of roughly five members in adult equivalents (AE). The average ages and years of formal education of household heads are 52 and 5.54 respectively. In terms of cocoa production, the average farm size is 7.23 ha, with an annual yield of 282.30 kg/ha. In terms of cocoa variety and tree age, 74% of the households indicated that they planted hybrid cocoa, and 54% indicated that they had young cocoa trees less than four years old. The average input usages were 3.39 kg/ha, 1.73 L/ha and 0.17 kg/ha for fertiliser, insecticide and fungicide respectively. Annual labour usage was 103.10 man hours/ha, with about 57% of that supplied by the household and neighbour-exchanged labour.

In terms of exposure to biotic and abiotic stress, the data indicates that the proportion of the households reporting events categorised as a disease, pest or abiotic stress were 54.5%, 49.0% and 4.2% respectively. The stress rates for the entire sample, measured as the percentage of the farm affected for one year, were 6.31%, 9.26% and 0.46% for events categorised as disease, pest or abiotic respectively. Figure 1 indicates that there were no statistical regional differences in stress rates for pests or abiotic events. However, Figure 1 also indicates that disease stress rates differ across regions. The Ashanti region had the lowest disease stress rate, estimated at 4.29%, which is statically lower than that recorded in the Brong Ahafo (7.31%) and Western (6.44%) regions.

Table 1: Descriptive statistics of selected variables for cocoa-producing households in Ghana, 2002 to 2006

Variable	Mean	Standard deviation
Household size in AE	4.54	2.06
Household dependency ratio	0.82	1.22
Female head (yes = 1)	0.16	0.37
Age of household head (years)	52.19	14.71
Education of household head (years)	5.54	6.21
Cocoa area (ha)	7.23	7.58
Cocoa land owned (yes = 1)	0.66	0.46
Cocoa yield (kg/ha)	282.30	300.14
Hybrid trees (yes = 1)	0.74	0.44
Young trees (yes = 1)	0.54	0.50
Total labour use (man days/ha)	103.10	145.96
Household labour in total labour (ratio)	0.57	0.35
Fertiliser used (kg/ha)	3.39	9.55
Insecticide used (L/ha)	1.73	3.30
Fungicide used (kg/ha)	0.17	1.54
Credit access (yes = 1)	0.32	0.47
Cell phone access (yes = 1)	0.02	0.15
Spraying equipment (yes = 1)		
No spraying equipment	0.80	0.40
Only knapsack sprayer	0.04	0.20
Only motorised	0.13	0.34
Both knapsack and motorised	0.02	0.15
Transport asset (yes = 1)		
No transportation asset	0.53	0.50
Only bicycle	0.30	0.46
Only motorbike	0.01	0.08
Both bicycle and motorbike	0.16	0.37
Stress rate (% of farm × year)		
Disease	6.31	11.12
Pest	9.26	17.01
Abiotic	0.46	3.58

Sample size = 1 353

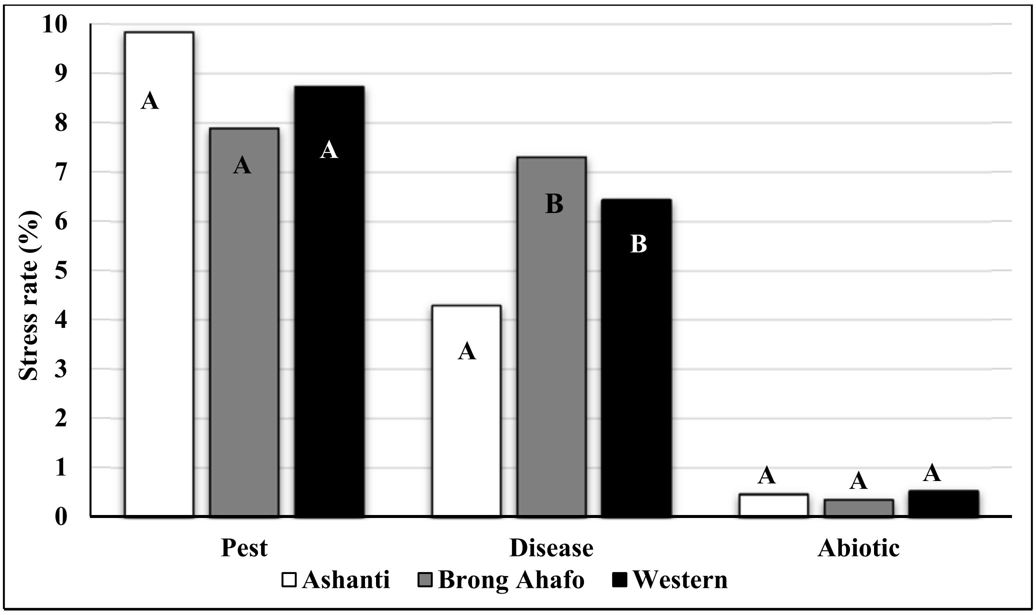

Figure 1: Regional differences in biotic and abiotic stress exposure in Ghana, 2002 to 2006
Stress rate is measured as the percentage of the farm affected that persists for a year
Stress indicators represented by the same letter are not statistically different at the 5% level

3. Results and discussion – Impact of biotic and abiotic stress on cocoa-producing households in Ghana

The regression estimates from Equation 1 are displayed in Table 2. The coefficients of determination (R^2) indicate that 29.10% of the variation in the natural log of cocoa yield is explained by the variation in the independent variables used in the model. The relatively low value of the R^2 is a reflection of the cross-sectional nature of the sample. The model F test statistics – provided at the bottom of Table 2 – indicate that the model is significant. In addition, heteroscedasticity should be at a minimum because the estimated standard errors are clustered for each farmer. The hypothesis was rejected that there was no significant effect of biotic stress classified as a disease on cocoa yield (kg/ha) (Table 2). The estimated disease elasticity of cocoa yield from Equation 2 indicates that, for every one percent increase in the proportion of the farm affected by disease for a year, the cocoa yields declined significantly, by 0.042%. In the case of abiotic stresses, i.e. drought and flood, cocoa yields declined significantly, by 0.003%. The study notably failed to reject the null hypothesis of no effect of pest stress on cocoa productivity.

In terms of the other covariates, for every one percent increase in farm size, production decreased significantly, by 0.35%. Labour use and the share of household labour in total labour were both insignificant. In addition, the interaction between the share of household labour and total labour usage was also insignificant. In terms of non-labour inputs, for every one percent increase in the use of fertiliser and insecticide, cocoa yield increased by 0.12% and 0.20% respectively. The sign of the estimated coefficient for farm size, fertiliser and insecticide were similar to existing studies on cocoa productivity in Ghana (Wood & Lass 1987; Edwin and Masters 2005; Aneani & Ofori-Frimpong 2013; Tsiboe *et al*. 2016).

Table 2: Regression results for selected covariates [a]

Variable	Coefficient	Robust standard error
Estimated responsiveness of cocoa yield to stress		
Disease	-0.042**	0.016
Pest	-0.013	0.013
Abiotic	-0.003*	0.002
Estimated marginal effect of independent variables		
Stress rate (proportion of farm/year)		
Disease	-0.008***	0.003
Pest	-0.002	0.001
Abiotic	-0.012**	0.005
Cocoa area in log [(ha)]	-0.353***	0.041
Cocoa land owned (yes = 1)	0.062	0.058
Hybrid trees (yes = 1)	0.062	0.055
Young trees (yes = 1)	-0.250***	0.050
Total labour use in log [(man days/ha)] [A]	-0.011	0.057
Household labour in total labour (ratio) [B]	-0.017	0.259
Interaction between [A] and [B]	-0.036	0.058
Fertiliser use in log [(kg/ha)]	0.121***	0.020
Insecticide use in log [(L/ha)]	0.202***	0.039
Fungicide use in log [(kg/ha)]	0.123	0.077
Spraying equipment		
Only knapsack sprayer	0.233***	0.089
Only motorised	0.228***	0.062
Both knapsack and motorised	0.399***	0.113
Transport asset		
Only bicycle	0.145**	0.064
Only motorbike	0.274	0.183
Both bicycle and motorbike	0.381***	0.092
Cell phone access (yes = 1)	0.253**	0.119
Household size in log [(AE)]	0.117***	0.045
Household dependency ratio	-0.033**	0.016
Female head (yes = 1)	-0.116*	0.067
Education of household head in log [(years)]	0.040*	0.022
Credit access (yes = 1)	-0.071	0.047
Constant	5.554***	0.305
Sample size	1353	
R^2 (%)	29.10	
Model F-test	20.910***	

[a] Values in the above table were calculated based on all statistically significant digits; however, given space constraints, all statistically significant variables could not be reported but are available from the author upon request
Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.0$.
Standard errors adjusted for clustering at household level for robustness against heteroscedasticity
Full estimation results and the SATA codes for the analysis are available upon request

With regard to the negative relationship between cocoa yield and farm size, Benjamin (1995) poses the relationship to be a result of labour market imperfections. Because of limited opportunities for employment on relatively larger farms, smallholder farmers can only employ their labour on their own farms; hence, yields tend to be higher on smaller farms because the farmers have more labour per hectare (Teal *et al*. 2006). The use of fertiliser, insecticides and fungicides enhance yields, given that fertiliser improves soil quality, and insecticides and fungicide eradicate pests and fungi that can cause yield losses.

Those producers with young cocoa trees (ages zero to four years) have significantly lower yields, by 22.10%; this follows logically because cocoa trees take three to five years to yield their first crop (Wood & Lass 1987). Alternatively, peak yield for cocoa occurs at 15 to 25 years after establishment, with a profitable life of 50 years (Montgomery 1981). However, profits decline beyond 26 years. In terms of production equipment, Table 2 shows that households with at least one type of spraying equipment, such as a knapsack or motorised sprayer, yield 25.96% more cocoa on average, with these producers yielding 49.07% more those with access to neither these types of spraying equipment. Having spraying equipment enables farmers to adequately apply agrochemicals on their farms, which ultimately helps minimise yield losses due to pests and diseases. In addition, having both a bicycle and a motorbike increases cocoa yields significantly – by 46.31%.

In terms of household characteristics, households with relatively higher dependency ratios yielded significantly less cocoa than those with lower dependency ratios. Households headed by a female yielded significantly less cocoa (10.93%) than those headed by a male. The gender gap in several dimensions is not limited to productivity only. This gap can be traced to the social status of males versus females in most African societies; the social status determines which of the two genders is preferred during the selection of land ownership and credit support. To minimise the occurrence of the gender gap, a global movement backed by leading firms in the world's cocoa and chocolate industry is attempting to ensure that women in cocoa-growing communities are empowered. Examples of programmes aimed at empowering women in cocoa-growing communities are Cocoa Action and the Cocoa Livelihood Programme, both implemented under the protection of the World Cocoa Foundation (WCF 2015a; 2015b).

4. Conclusion and recommendations

Using a quasi-panel household-level data sample of Ghanaian cocoa farmers, our study incorporated a regression model to estimate the responsiveness of household cocoa yield to biotic and abiotic stresses. For biotic stress categorised as disease, cocoa yield declined by 0.042% for every percent increase in the annual proportion of the farm affected; and for abiotic stress (drought and flood), yield declined by 0.003% for every percent increase in the annual proportion of the farm affected. However, the results showed no significant yield response to biotic stress categorised as pests. The descriptive statistics show that, among the three stress variables, pest stress has the highest rate. On average, 9.29% of cocoa farms are affected by a pest stress that lasts for one year. As such, our study recommends that the government of Ghana should consider expanding the scope of the National Cocoa Diseases and Pest Control (CODAPEC) programme, popularly known as "mass spraying". Currently, CODAPEC is targeted at only controlling capsid/mirid and the black pod fungi. While CODAPEC exists solely to help cocoa farmers deal with biotic stress, to the best of our knowledge there are no programmes to help farmers deal with abiotic stresses that affect cocoa production, such as droughts and floods.

Droughts, and occasionally floods, are major agriculture challenges in Ghana, leaving farmers economically disabled by wiping out farms and preventing plantings in the subsequent season. As a result, the Ghana Agricultural Insurance Programme (GAIP) was launched in 2011 to protect farmers against financial risks from the negative impacts of climate change. Currently, GAIP has drought index insurance for maize, soya, sorghum and millet, but no product for cocoa. Thus, as a second recommendation, GAIP should develop an insurance product for cocoa to help farmers manage the risks of abiotic stresses.

Finally, because extensive cocoa datasets are limited, only a few studies in the literature have observed the impact of biotic stress, and none have highlighted the impact of abiotic stress on cocoa-growing households. Consequently, continuous research on the impact of biotic and abiotic stress on cocoa yields is crucial for policy initiatives, especially in Ghana, where the annual government mass cocoa-spraying exercise is on the decline. From an economic standpoint, this study provides several important findings. First, it appears that disease reduction can have relatively large effects on increasing cocoa yields. Therefore, funds provided by the government of Ghana to control cocoa swollen-shoot virus (CSSV) and black pod fungus are helpful in combatting increases in disease and threats to household livelihoods. Second, the private and public sectors could focus on resistance to biotic and abiotic stresses as a way to both increase yield and reduce yield instability, both of which increase producers' economic livelihoods, although bearing in mind that many agricultural producers in low-income countries value increased yield stability as much as increased yield potential research and development funding.

Research to alleviate poverty often tends to focus on the yield potential (ceilings) of varieties instead of variability (floors), and thus often may undervalue the genetic resistance to abiotic/biotic stresses that do not raise yield potential, but raise the yield floor. In other words, money invested in cocoa varieties that are resistant to specific biotic/abiotic stresses does not raise the yield potential of a given variety, because biotic/abiotic stresses manifest in most growing seasons, and yield potential is derived from a best-case scenario. However, biotic/abiotic stress resistance does in fact reduce the yield variability (floor) of a variety. Consequently, this study has helped shed light on the value of raising the often overlooked "yield floor" through biotic/abiotic stress resistance and the treatment of an outbreak if it occurs at the household level.

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