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Research

Addressing the resilience of tomato farmers in Ghana facing a double exposure from climate and market

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ABSTRACT. Ghanaian tomato farmers are severely impacted by changing climate and related more frequent and extreme weather events such as drought and heavy rainfall. Furthermore, tomato production represents one of the main sources of income for these farmers, which leaves them highly exposed to market price variations. However, the full impact of changing climate and price variations for these farmers has not been assessed. Here, we examined how Ghanaian tomato farmers experience and respond to a double exposure from climate and market related shocks. The objectives were threefold: (i) to investigate how farmers in two different agroecological zones (savannah and semi-equatorial) experience climate and market shocks, (ii) to examine the major response strategies implemented in face of this double exposure, and (iii) to identify paths toward systemic changes to enhance resilience. A survey was conducted with 344 tomato smallholder farmers in the two agroecological zones. The results from the survey were complemented by semi-structured interviews and focus groups. We found that farmers are severely exposed to climate and market shocks, which causes a reduction in both production activities and revenues. A set of agricultural and water management practices, such as crop rotation, supplementary fertilization, and water tanks, have been adopted by farmers as response mechanisms to climate variations. However, no response mechanisms, other than agricultural diversification, are in place yet to face the economic shocks. Thus, enhancing systemic resilience becomes particularly important to face this double exposure and restructure and change feedback mechanisms within the current system. The reestablishment of tomato processing plants or formalizing the stakeholders' network could both be ways to integrate value-chain stakeholders and support appropriate structures. Encompassing both climate and trading attributes through specific agro-food policies are much-needed for a sustainable and resilient transformation of the tomato production system.

Key Words: *climate change; Ghana; market; resilience; social-ecological system; tomato; transformation*

INTRODUCTION

Horticultural farmers are increasingly facing the negative effects of climate change on their production. This is particularly the case in sub-Saharan Africa where horticultural crop irrigation is mainly dependent on rainfall and thus highly sensitive to climate variations (Guodaar et al. 2016). In recent years, droughts, heavy rains, and increasing temperatures have strongly contributed to a reduction of water availability, soil quality, and increased frequency of pests and crop diseases (Asante and Amuakwa-Mensah 2015, Williams et al. 2019). At a market level, infrastructure, connectivity, and demand are important factors influencing price fixation (Amikuzuno and von Cramon-Taubadel 2012). In sub-Saharan Africa, poor infrastructure or transport network are viewed as key obstacles to equity in the region (Calderón and Servén 2010, Marandure et al. 2020). However, global trade also affects price fixation and triggers distortion in the establishment of the price at a local level (Adimabuno 2010). Horticultural farmers face then a double exposure on both farm and market levels. This agricultural system is thus highly interconnected and it is argued in this paper that in order to enhance farmers' resilience, there is a need to understand the structure and feedback mechanisms within this system.

Enhancing climate resilience for smallholders farmers has been addressed over the last decade (Abraham et al. 2014, Aldunce et al. 2015, Tendall et al. 2015, Ali et al. 2016, Tambo 2016). Resilience is tied to a disturbance, which encompasses both a short-term shock and a long-term stressor. Meuwissen et al. (2019) suggest three attributes of resilience to address the resilience of farmers: robustness, adaptability, and transformability. Robustness is understood as the ability of the system to withstand disturbances (Folke 2006). Adaptive capacity is the capacity of a social-ecological system to adjust its responses to changing external drivers and internal processes. Finally, transformability is the capacity to create new stability domains for development, a new stability landscape, and cross thresholds into a new development trajectory.

Although resilience thinking grew out of a desire to be holistic, the challenge to holistically approach such an interconnected system is substantial. Systemic thinking for agricultural systems has received growing attention over the last years through the use of system dynamics (Banson et al. 2014, Gerber 2016, Kotir et al. 2016, Kopainsky et al. 2017, 2019) or via a participatory approach (Helfgott 2018, Ulrichs et al. 2019). Agricultural systems are social-ecological systems characterized by biophysical and socioeconomic factors linked through feedback mechanisms (Berkes et al. 2008). This study is a continuation of previous systems approaches (Gerber 2016, Herrera 2017, Kopainsky et al. 2017) based on the interconnections and feedback mechanisms within a system to offer a possibility to step beyond climate adaptation to enhance resilience through a systemic approach.

In Ghana, tomatoes are an important ingredient for the average diet and are consumed in large quantities, both fresh and in the form of concentrate as paste (Frimpong Boamah and Sumberg 2019). Approximately 440,000 tons of tomato are consumed annually, with domestic production not entirely keeping up with

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the demand of around 420,000 tons in 2019 (FAO 2019). Also, tomato production is one of the main sources of income for a large number of horticultural producers (Wossen and Berger 2015, Ecker 2018). Ashanti and Upper East Region are among the two main regions known for tomato production (Robinson and Kolavalli 2010a). The production of tomatoes is largely carried out on family farms of relatively small size (0.5–1.2 ha) on open fields with low use of machinery and fertilizers. The high water requirements for tomato production makes it vulnerable to extreme climatic events, such as droughts but also heavy rainfalls and floods (Guodaar et al. 2016). Farmers are therefore facing agronomic challenges due to climate change, which are then coupled with market challenges. Institutional support and public policies directed toward the tomato value chains sector has mostly focused on value-addition and large-scale processing in particular. However, very little attention has addressed tomato production and productivity, with no sustained effort to ensure viable and competitive tomato production or to provide the input required at a competitive price (Robinson and Kolavalli 2010b). In Ghana, tomato production has a pronounced seasonal pattern coupled with high price variability, which makes it difficult for farmers to secure their production and sales (Amikuzuno and von Cramon-Taubadel 2012). On the one hand, farmers are still inclined to take the risk of cultivating tomatoes despite the price volatilities and weather uncertainties because high prices at peak seasons allow them to substantially increase their income. On the other hand, farmers face a high degree of regional competition from neighboring countries such as Burkina Faso. This competition is further accentuated by globalized trade and the increasing import of tomato-derived products from China or Italy that affects local prices (Clottey et al. 2009, Laube et al. 2012). Moreover, within the country, disparities in terms of governmental support between the north and the south have been reported (Abdulai et al. 2018). Although special attention has been accorded to specific elements, such as the establishment of irrigation schemes, other support mechanisms for farmers' services and market support have been lacking in the northern regions. These differences between regions shape the responses to agricultural policies established by the public sector to support and improve the tomato sector from production to market (Robinson and Kolavalli 2010b). Within such context, this double exposure further pressures tomato farmers who are already struggling with low agricultural productivity, little investment, and limited ability to adapt to shocks (Wossen and Berger 2015).

Enhancing adaptive capacities in the face of climate events has received a lot of attention over the last decade, including for smallholder farmers in Ghana (Armah et al. 2011, Laube et al. 2012, Tambo 2016, Azumah et al. 2017, Antwi-Agyei et al. 2018). However, only a few studies refer to the role of market and market prices to support farmers season after season in enhancing their adaptive capacity (Tucker et al. 2010, Belay et al. 2017, Aboah et al. 2019). Ultimately, enhancing farmers' resilience is thus essential for addressing the double exposure of global environmental change and economic globalization.

Thus, the objectives of this study are threefold: (i) to investigate how farmers in two different agroecological systems experience climate and market shocks, (ii) to examine the major responses in the face of this double exposure, and (iii) to identify paths toward enhancing farmers resilience in the Ghanaian tomato production system.

METHODS

Survey methodology and data collection

For the purpose of the study, we relied on a resilience assessment based on a household survey conducted between May and June 2018. Hence, our assessment of resilience relates to an individual's cognitive and affective self-assessment of the capabilities and capacities of their household to respond to a disturbance and could be characterized as a subjective resilience assessment (Jones and Tanner 2017). More specifically, the survey invited farmers to self-assess their resilience against drought, heavy rainfall, and market price variability. The aim of the survey was to collect quantitative information. We identified households to survey and selected smallholders from the two different key producing areas (i.e., Ashanti and Upper East Region). Fourteen districts were selected with the support of the division of the Minister of Agriculture of the Region as the most noteworthy in terms of tomato production, and between 20 to 30 households in each district, also with the support of the division. Overall our sample consists of 344 households. The data was collected in face-to-face interviews, in the form of an offline tablet-based survey using Surveygizmo software (Boulder, CO, USA). The software enables the creation of tailor made questionnaires and records answers offline, very convenient when surveying in remote areas. The interviews were conducted with a team of five local student assistants (two in the Ashanti Region and three in the UER) who were trained and who supported all the interviews that were conducted in several local languages and in English. The questionnaire featured 71 questions divided into subtopics covering demographics, crop production, farm management, shock experience, income generation, community cooperation, and group membership. Each interview lasted between 30 and 45 min. Participation in the questionnaire was optional and all interviewed farmers were informed that these findings would be published and the answers could not be traced back to individual farmers. During the interview, farmers could cease to participate at any time.

Complementarily to the survey, we conducted a series of semi-structured interviews with local value chain stakeholders (e.g., input suppliers, farmers, agricultural extension officers, and traders) in order to deepen our understanding of the relations and interconnections amongst stakeholders, the services or goods that they provide in the chain, and the challenges they face regarding climate and market related shocks. Thus, the 34 in-depth interviews enabled us to have a comprehensive view of the system, to highlight the main issues within the system, and to elucidate the inner dynamics in a systemic manner. The audio records were then transcribed by the assistants: the responses of the interviewee were translated once again, word for word, with the aim of being as accurate as possible in the translation. The transcriptions were rather strict (to the extent possible given the translation), even though sometimes some interpretative comments were added: for example, comments in bracket were made when a person began to talk passionately about a subject. Last, as part of a complementary study focusing on the power relations within tomato value chains in the Upper East Region, a focus group was led in Navrongo with the different stakeholders

of the chain. This event also enabled us to gather justifications and testimonies. The stakeholders involved in this focus group were tomato farmers, traders, input suppliers, an extension officer, and NGO worker. The discussions with the stakeholders enabled us to identify potential pathways to improve their response to climate shock and enhance their resilience.

Systemic approach

We translated the information gathered in the survey and in the interviews into a systems map. To do so, we borrowed from the field of system dynamics to provide tools and techniques to understand the systems, that is, the feedback mechanisms, cross-scale linkages, cascading impacts, and potential trade-offs arising from their dynamics (Redman 2014). More specifically, we used a causal loop diagram (CLD) to reveal and map the interconnections within the system and to identify the main challenges that farmers have to face. A CLD is a conceptual tool in which a chain of cause-and-effect relationships is traced through a set of variables that characterize a dynamic issue (Kopainsky et al. 2017).

In order to understand how effects of these disturbances interact, and whether we can talk about double shocks as a combination of climate and market shock, we conducted a series of interviews with stakeholders and experts. We first chose to represent this dynamic system in a graphical and simplified way, in order to better understand the main structure of the agricultural system and the driving feedback mechanisms this study relies on. We documented each link amongst the actors and exogenous factors (such as shocks) with the interviews conducted and insights from the survey results.

Starting from the interview data, we inductively developed first hypotheses about the double exposure challenge through a CLD and highlighted the main feedback loops driving smallholder tomato producing system. These feedback mechanisms are found in agricultural systems and can be either reinforcing or balancing. We dissociated the nature of the relationships in three categories: (1) economic, characterized by money flow, (2) agronomic, characterized by agronomic practices, and (3) social, characterized by human interactions and decisions.

Operationalizing resilience

Assessing and building resilience of agriculture to climate change has become increasingly important over the last decade. However, there is still no consensus on how resilience should be assessed and what indicators should be used (Brand and Jax 2007, Douxchamps et al. 2017). Building on an existing framework to operationalize resilience (Folke et al. 2010), we distinguish three resilience attributes:

1. Robustness is seen as the ability to maintain desired levels of outputs despite the occurrence of perturbations (Tendall et al. 2015, Urruty et al. 2016)
2. Adaptability is seen as the capacity to change the composition of a function that could be input use, production, or marketing in response to shocks and stresses (Tendall et al. 2015, Meuwissen et al. 2019).
3. Transformability could be understood as a way to extract the subject (e.g., farmer) from a situation where adaptability is not always enough to recover from one or many repetitive shocks.

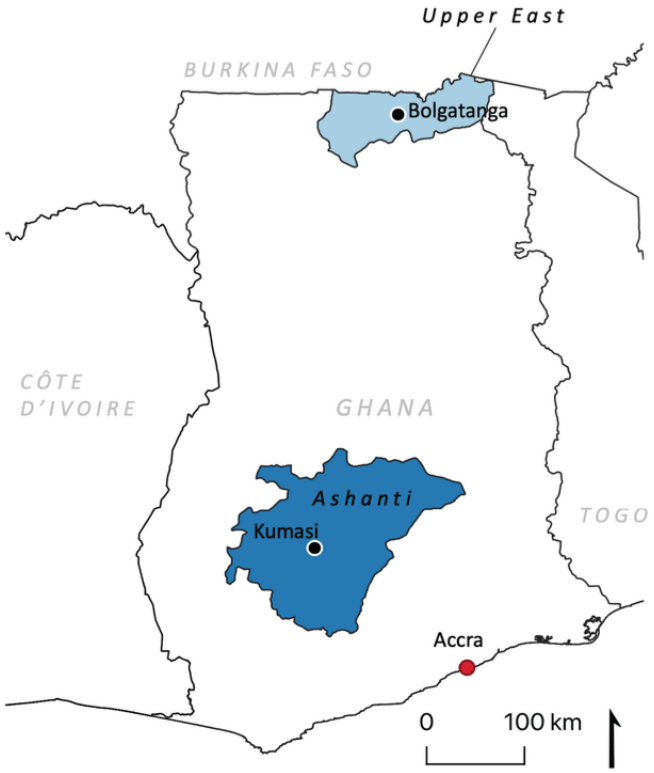
Study Area

For this study, we chose to focus on two key tomato producing areas. The choice of Upper East region and Ashanti was motivated by (a) the diversity of their agroecological zones, that would enable us to observe different climate patterns and reactions, and (b) the connections and proximity to markets and consumers that would enable us to observe potential differences in market price fixation and volatility.

Upper East region

The Upper East Region (UER) is located in the extreme northeast of Ghana (Fig. 1), bordered by both Togo and Burkina Faso, in the savanna agroecological zone (Armah et al. 2011). The region is characterized by unimodal rainfall patterns starting in May and ending in September, and brings rainfall averaging 950 mm per annum. The majority of the households (76.4%) are located in rural areas (Antwi-Agyei et al. 2012) and agriculture, mostly rain-fed, is the predominant economic activity (Kumasi et al. 2019). During the rainy season, farmers produce staple grains such as maize, millet, sorghum, and rice (Fagariba et al. 2018) for both self-sufficiency and sale, whereas in the dry season farmers mostly grow irrigated vegetables, such as tomatoes, onions, and peppers. Farmers using irrigation find their main source of income through the sale of these high-value vegetables during the dry-season (Abdulai et al. 2018). Irrigation is here characterized by the process of fetching and supplying water from small damns that get refilled through rainfall events.

Fig. 1. Map of Ghana and its two main tomato producing regions (Ashanti and Upper East Region).



Northern Ghana has received particular attention in the scientific literature over the last decades because the region remains one of the most vulnerable in the face of climate change. The region is known to have the highest prevalence of poverty and food insecurity in the country (Abdulai et al. 2018, Fagariba et al. 2018, Adu et al. 2018).

Ashanti region

Ashanti is a region located in southern Ghana with a double maxima rainfall regime, typical of semi-equatorial zones. The major rainfall season starts around April and ends around June, while the minor season stretches from September to October, with annual rainfall averaging 1600 mm. In Ashanti, about 62% of the population is engaged in agriculture (Guodaar et al. 2016). The capital of the region, Kumasi, has the largest open air market in the country, and West Africa, and is an important hub for the trading of agricultural products (Probst et al. 2010). In Ashanti, farmers produce maize and cassava or groundnuts for sale, whereas in the dry season farmers also mostly grow irrigated vegetables, such as tomatoes, cabbage, and peppers. With the double maxima rainfall regime, some farmers are producing tomato up to three times a year.

Because of the complementarity of these two agroecological zones and consequently rainy seasons, tomato production in Ghana is characterized by a pronounced seasonal pattern (Amikuzuno and von Cramon-Taubadel 2012). From June to December the main suppliers are located around the Ashanti and Brong-Ahafo regions producing rain-fed tomatoes that are able to supply the country's demands; from December to April, during the dry season, the main national suppliers are found in the UER, near Navrongo, through irrigation (Britwum 2013).

RESULTS

Household characteristics

In both regions, the majority of the respondent were male, 84.1% in Ashanti and 69.1% in UER, and most owned their farm: 74.4% in Ashanti and 65.7% in UER (Table 1). The average farm size is bigger in Ashanti, with an average of 3.8 ha with 0.9 ha allocated to tomato production, compared to 1.8 ha with 0.5 ha allocated for tomato production in UER. Forty-seven percent of the farmers surveyed in Ashanti reported a total household income of less than 6250 GHc (= 1084 US$) per year, whereas the ratio in UER is higher at 77%. This level is presented as a cut-off, below which the household is considered to be under the global poverty line (World Bank 2015). T-tests (and p-values) show significant differences between tomato producers of the two regions. In this survey, most of the respondents were male, which reflects findings of studies that tomatoes are disproportionately grown on plots held by men (Doss 2002). When it comes to tomato value chains, women are dominating the trading market and are commonly called "tomato queens" (Adimabuno 2010).

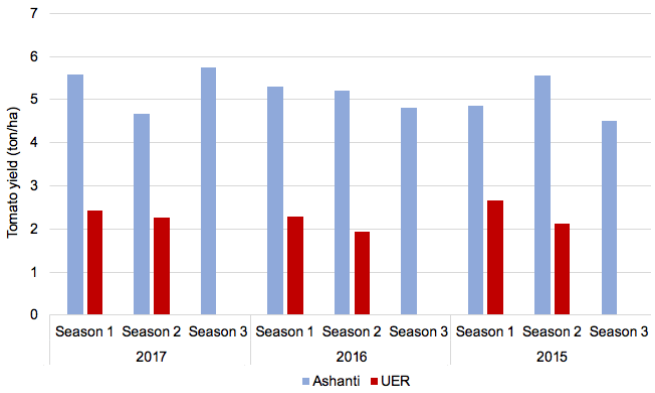
Yields and accessibility of goods and services

First, tomato production per season indicates, on the one hand, that Ashanti farmers produce tomatoes up to three times a year, whereas in UER, farmers can only manage to produce tomatoes twice a year. On the other hand, we observed that average yields are up to 2 times lower for farmers in UER, with an average yield of 2.3 t/ha (Fig. 2), whereas it reaches 5.3 t/ha in Ashanti. Moreover, tomato yields from the farmers surveyed indicated that they were very low, and much lower than some studies report, i.e., from 5 to 14 t/ha (Robinson and Kolavalli 2010a), and all the more compared to a potential yield of 45 to 65 t/ha under irrigation, according to the FAO, for open-field tomato production at a global scale (FAOStat 2021). These differences could be explained by the agricultural management practices, where farmers are not following the best management practices in terms of agroecological practices or input use. Moreover, the poor quality of seeds or poor soil quality conditions can also play a crucial role in the productivity.

Table 1. Household Characteristics for the Ashanti region (n=164) and the Upper-East region (n=178)

	Ashanti	Upper East Region	p value
Sex			0.001
Female	15.9%	30.9%	
Male	84.1%	69.1%	
Relation to Farm			< 0.001
Owner of the farm	74.4%	65.7%	
Other	25.6%	34.3%	
Years of experience: mean (SD)	19.9 (11.2)	17.3 (12.5)	0.045
Household size: mean (SD)	8.4 (6.3)	5.9 (3.0)	< 0.001
Education			< 0.001
No school education	22.6%	44.9%	
Secondary school	39.0%	16.3%	
Other	38.4%	38.8%	
Total household income			< 0.001
< 6250 Ghc	47.0%	77 %	
> 6250 Ghc	53%	23 %	
Farm size: mean (SD) in hectares	3.8 (3.2)	1.8 (1.3)	< 0.001

Fig. 2. Average tomato yields (wet weight) per season per region: Ashanti and Upper East Region.



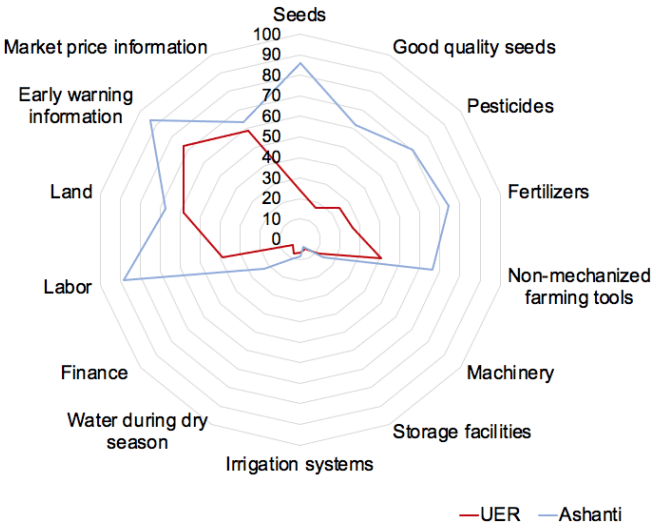
Consequently, we focused on the access to technology, inputs, water, capital, market, labor, and knowledge (Fig. 3). The results of our survey show that although some farmers have access to agricultural inputs (e.g., seeds, pesticides, fertilizers, etc.), it is

Table 2. Percentage of farmers experiencing a climate shock (drought and/or heavy rainfall) over the last 3 years and the perceived consequences (data collected from the survey).

	Farmers experiencing a shock		Collateral effects experienced during the shock		
Region	Nature of the Shock		Water scarcity	Reduced productivity	Less income
Ashanti	Drought	93.9%	91.6%	87.7%	87.7%
	Heavy rainfall	82.9%	0.7%	80.9%	65.2%
Upper East Region	Drought	82.9%	89.7%	80.9%	74.7%
	Heavy rainfall	80%	2.1%	58.3%	34.8%

more difficult for them to access financial capital and technologies such as irrigation systems or storage facilities. Indeed, we see that during the dry season water is barely accessible for farmers and they do not have access to irrigation systems either. Additionally, we found significant differences between the two regions: farmers from UER struggle more to access goods and services (Fig. 3) than those from the Ashanti region.

Fig. 3. Percentage of tomato farmers who have easy access to various goods and service: Ashanti (in blue) and Upper East Region (in red).



Climate exposure

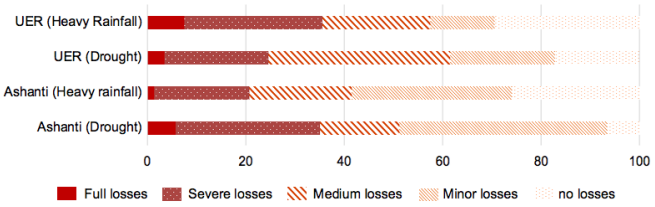
Experiencing a climate shock

Concerning climate-related shock, results from the survey confirmed that 93.9% in Ashanti and 82.9% in UER of the farmers experienced drought over the last 3 years (Table 2). The main implications of droughts, according to the respondents, were an increased water scarcity (for 91.6% of the respondents in Ashanti), a reduced tomato productivity (87.7% in Ashanti), and a decrease of their household income (with 87.7% in Ashanti). In UER similar patterns were observed, with 89.7% of the respondents experiencing water scarcity in UER, 79.5% of the farmers identifying a reduction of their tomato production, and 74.7% a reduction of income.

Farmers in both regions have also experienced heavy rainfalls, with 82.9% in Ashanti and 80% in UER. Heavy rainfalls similarly lead to reductions in tomato production and impact farmers' income in both regions (Table 2). The results show that more farmers in Ashanti experienced losses in their productivity and income than UER farmers.

When asked to estimate the magnitude of yield losses caused by droughts, 35% in Ashanti and 24.6% in UER reported full or severe losses (Fig. 4). In case of heavy rainfalls, a similar range of impacts were reported: 20.8% in Ashanti and 35.6% in UER reported severe to full tomato yield losses.

Fig. 4. Reported magnitude of tomato yield losses after a climate shock in Ashanti and Upper East Region.



These results demonstrate high exposure of tomato farmers to climate extreme events. It also highlights that smallholder horticultural farmers' production activities are climate sensitive. Climate related shocks clearly have direct negative impacts on their livelihoods. These losses also show the lack of robustness of farmers in the face of a shock. Their capacity to withstand a shock is questioned by their inability to access services and inputs.

Responding to a climate shock

At the farm level, a range of soil and water practices are contributing to maintain the quality of the soil and the agroecosystem that can help farmers cope with climate shocks. Horticultural crops have a rather short growing season, which enables more flexibility in planting patterns and practices. Based on the survey, we identified agronomic response mechanisms employed by smallholders' farmers to cope with climate shocks (Table 3). As an example, 78.8% of the UER farmers implemented adaptation practices to cope with drought, where 28.1% delayed the planting time for their tomato crops and 22.6% switched to another crop, like pepper. In Ashanti, only 65.6% declared implementing changes to cope with the drought and 42.6% for heavy rainfall. Seasonal migration off-farm, as an off-farm

Fig. 5. Water (in blue), agricultural (in green), and socioeconomic management practices (in orange) used in Ashanti (bars with lines) and in Upper East Region (plain bars). P value < 0.001 for the comparison between regions when (*) is indicated above the columns.

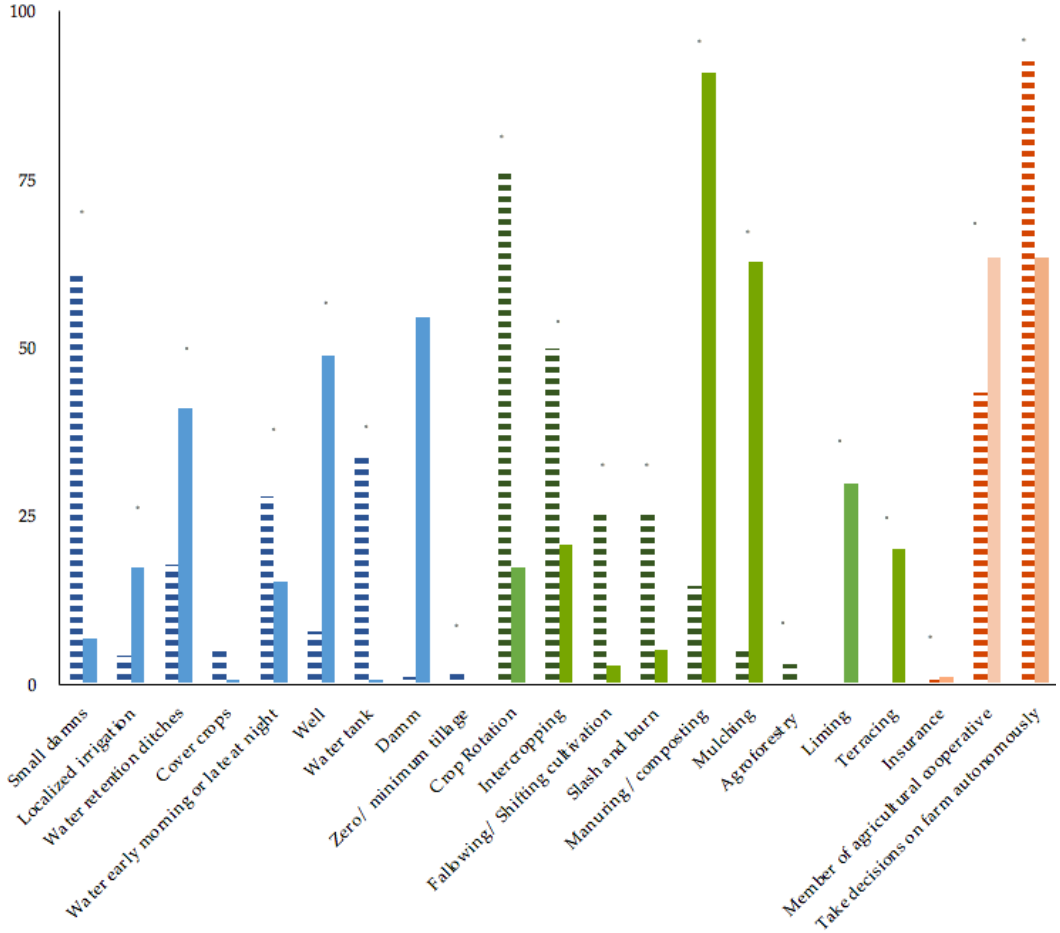


Table 3. Farmers' responses to climate shocks (i.e., drought and heavy rainfall); % express the share of the farmers included in each region.

	Ashanti		Upper East Region	
	Drought	Heavy rainfall	Drought	Heavy rainfall
Implemented changes to cope with the shock	65.6%	42.6%	78.8%	66.7%
Implement different water management practices	36.4%	9.6%	30.1%	17.4%
Delay the planting	8.4%	3.7%	28.1%	7.6%
Change the crop	5.2%	9.6%	22.6%	30.6%
Migration off-farm	0.0%	0.7%	2.7%	7.6%

economic activity and an alternative source of income, does not appear to be an adaptation option for most of the farmers.

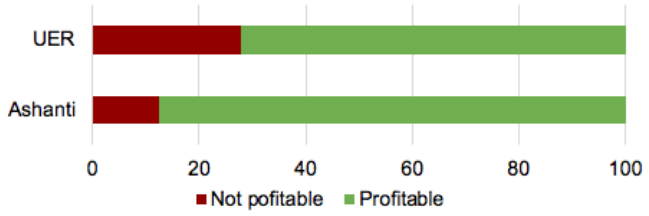
In both regions, farmers use a diverse spectrum of water, agronomic, and socioeconomic management practices (Fig. 5). The most prevailing adaptation practices identified in UER include composting or manuring, mulching, liming, and intercropping for agricultural management, and supplementary irrigation through dam and wells for water management. In Ashanti, 76.2% of the surveyed farmers apply crop rotation and 50% use intercropping as agricultural management adaptations. In terms of water management, small dams and the use of a water tank are implemented to better fulfill water needs. Moreover, 63.5% and 92.7% of the UER and Ashanti farmers, respectively, stated that they are able to implement these changes autonomously. The farmers facilitated these changes individually by expending their own social capital and resources. Overall, we found some clear differences in adaptation responses between the two regions. On the one hand, this difference can be explained by the agroecological conditions, but on the other hand, the observed difference can indicate an imbalanced agricultural governance between the two regions.

Market exposure

Experiencing market pressures

Tomato is a high value crop and can be considered for some smallholder producers as a source of income, even though all of the surveyed farmers diversify their production with other vegetables (e.g., pepper, cabbage, onion), cereals, maize, or livestock. In Ashanti, 72% of the surveyed farmers reported that tomato is the 1st source of income in their household, while in UER this is the case for only 30.3% of farmers. In the UER, the main source of income stems from another crop for 56.7% of the farmers. Moreover, 27% of the farmers had declared not extracting any profit over the last 3 years when selling tomato in the UER; in contrast, only 12.6% of Ashanti farmers reported this (Fig. 6). Farmers reported that expenses for production were higher than the revenues generated mostly because of low market prices. These results indicate that the potential, rather than the real, high profitability of the crop drives farmers to take the risk of producing it over the years even though they may run at losses sometimes. However, it also shows that a significant portion of the farmers have not been able to extract the expected profitability from their production and thus indicates that farmers are highly exposed to market structure and prices.

Fig. 6. Average % of farmers generating profitability from tomato sales between 2015 and 2017 in Ashanti and Upper East Region.

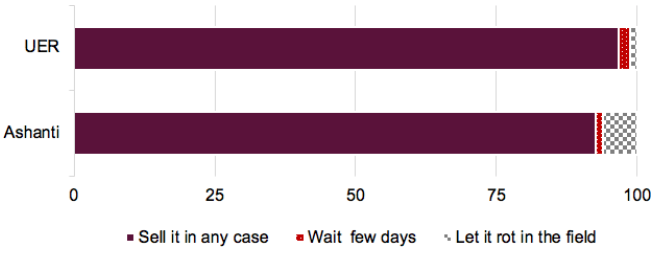


Responding to market variability

A price shock for a farmer is translated in low farm gate prices. Horticultural crops are highly perishable, which gives farmers very little room for flexibility by, e.g., storing them. When asked what strategies they adopt when farm gate prices are too low, the majority of farmers (92.7% in Ashanti and 96.6% in UER) answered that they sell their produce anyway (Fig. 7). The other options suggested in the survey, but very infrequently chosen by the farmers, were either to wait a few days or leave the produce to rot in the field, which also leads to loss of income for the season (Fig. 7).

These results together indicate that farmers are highly exposed to market price variation and, more importantly, are unable to develop any mechanisms to withstand low tomato prices. Consequently, the results of the survey demonstrate that farmers are exposed to both climatic and market related shocks. Also, the majority of farmers show no robustness in the face of shocks as the impacts perceived are direct, with the effects of backlashing on their income generation. On the other hand, farmers build up only little to no adaption practices to withstand the climatic extreme events (i.e., drought and heavy rainfall). These first survey results urged us to zoom out and focus on the whole system including farm and market dynamics.

Fig. 7. Response strategies when farm gate tomato prices are too low.



Systemic interconnections

Based on the survey and interviews with stakeholders and experts we identified three major feedback loops to be represented in our causal loop diagram (Table 4). The systems map that we built is a simplified version of the situation; the aim is to allow us to facilitate an understanding of the structure of the system and its interdependencies (Fig. 8):

1. Reinforcing loop - R: The more cash a household has available, the more inputs (fertilizer, seed, herbicides, irrigation facilities) they can purchase. More inputs allow farmers to cultivate more land and thus increase the amount of food they produce, through higher crop yield. Because tomato is a cash crop, it is sold directly, generating more sales, and thus more income, which adds to the stock of cash.

2. Balancing loop - B: More tomatoes sold on the market can decrease the price of the crop at farm gate, reducing subsequently the revenues generated by the production of the crop. Additionally, in UER, Burkina Faso appears to be a major informal competitor influencing the prices on the market.

3. Balancing loop - B': More cash spent on inputs is decreasing the amount of cash available for the household.

Thus, the negative impact of a climatic shock on the system can be twofold: (1) either it can reduce the loop strength and dominance, i.e., with lower irrigation and water intake, the crop yield decreases; or (2) it can reverse loop direction of the system, i.e., farmers increase their input expenditure to counteract the expected yield decrease due to the climate shock, thereby further decreasing their household available cash for food and inputs of the next year; the latter in turn leading to yield decreases. Furthermore, the CLD shows that market shocks reinforce the balancing loop, limiting the revenues from tomato production. As a result, even though farmers implement climate mitigating agronomic and socioeconomic practices, they are not exempt from market pressures at the farm gate. As a matter of fact, even though regional crop production decreases because of climate stresses, tomato prices are not guaranteed to balance the shortfall. It is the additional supply of tomatoes (and tomato-derived products) from global trade that leads to a reduction of tomato prices at the same time that a drought or heavy rainfalls hits the

Table 4. System interconnections justifications through interviews gathered among actor from the tomato value chain

		Source[†]
Reinforcing loop R		
Inputs expenses and effects on yield		
	"We get help from the input suppliers; we take on credit and pay later."	14, Tomato farmer - NGO worker
	"The tomatoes we farm during the rainy season, I have some seeds so that when it rains again and you're going to farm, I will plant them."	16, Farmer
	"The way the tomato is, we farm it around the rainy season and if it doesn't rain but there is water around, like in small rivers and dams, we go and fetch the water from those places to come and water our garden."	17, Farmer
Climate effects on yields		
	"We are all based on the rain. The time we needed it, it didn't come and when it's time for us to do dry season farming, the rain was also worrying. When you plant, the rain would come and spoil everything. So, the rain has worried all of us.",	Focus group
Balancing loop B		
Sales on price		
	"If the market is there, you have to pluck all and sell but if there's no market and you bring it to the market and they don't buy, you reduce it for them."	5, Input supplier
Market transaction		
	"Like if we had a place where we can keep the tomatoes and they won't spoil or the tomato company where we harvest and they buy it, it has a lot of help, it improves our farming."	5, Input supplier
	"So, if they say this basin is 20 cedis and everyone is buying it at 20 cedis and you come late and say it's 30 cedis, who would buy from you? You have to take it as it is."	16, Farmer
	"The tomatoes in the dry season, we always farmed it plenty. And when we always farmed, and they come from Kumasi, to buy from us but when they started Ouagia [Ouaga, Burkina Faso], even when you farm, they don't want. They won't even mind you"	16, Farmer
Global trade on price		
	"People come to buy so we farm and you see that they don't come again to buy our tomatoes, that is why the farming of tomatoes has gone down."	5, Input supplier
	"Now where is the tomato [trader going] to? And they have started going to Ouagia [Ouaga, Burkina Faso] so they don't even come here, they go to Ouagia."	16, Farmer

[†]Interview number

production. Within this system's structure and with the presented feedback mechanisms of the farming system, enhancing resilience for farmers becomes all the more challenging.

Reflecting through systemic resilience

The objective of our study was to investigate how tomato farmers in Ashanti and UER experience and respond to climate and market shocks and to elucidate the major interactions between the shocks. We also focus on the three resilience attributes, i.e., robustness, adaptability, and transformability.

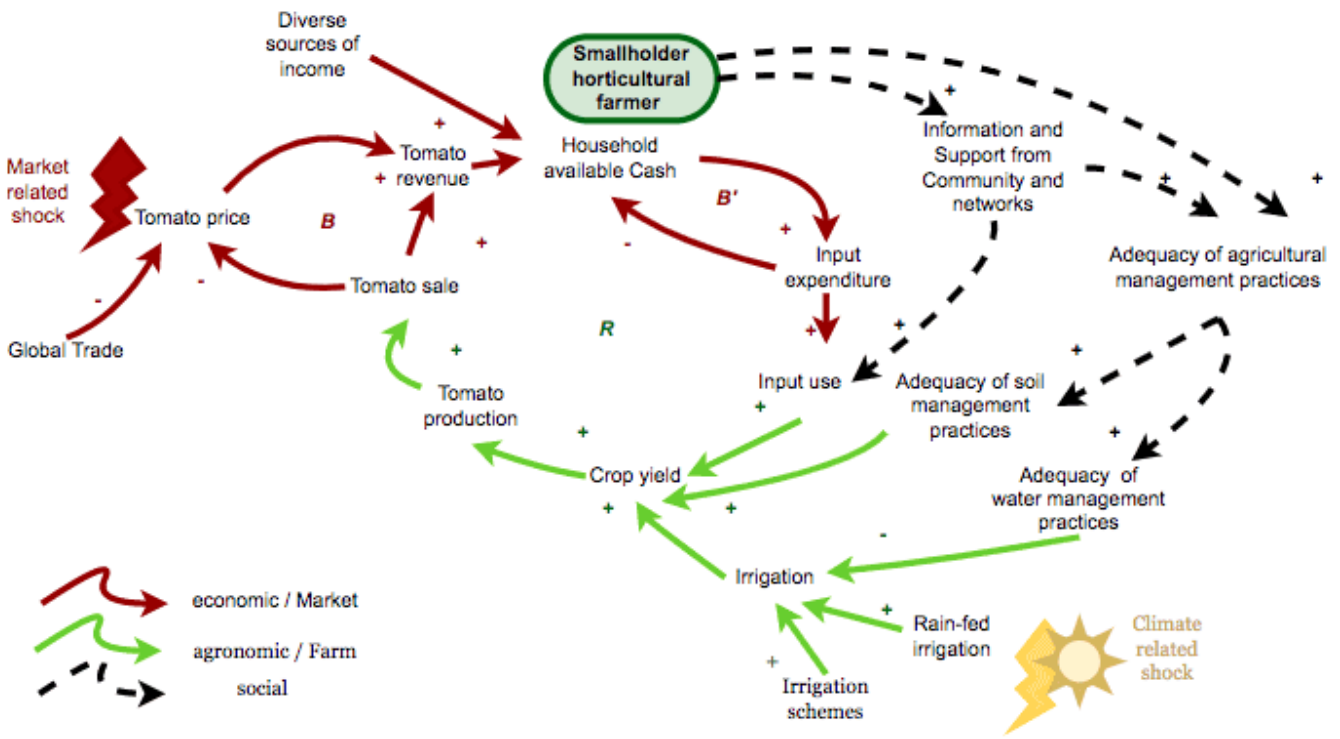
Robustness

In this study, maintaining crop yield or household income appeared to be a challenging task for the majority of the farmers. Yield losses (Fig. 4) and unprofitable production (Fig. 6) highlighted a lack of robustness (Tendall et al. 2015, Urruty et al. 2016). On the one hand, the results from this study could be mostly explained, like in Baba et al. (2013), by a lack of access and affordability of good quality seeds, inputs such as fertilizers, and irrigation infrastructures. In this study, we maintain a definition of access to goods and services and supply as "the ability to derive benefits from things" (Ribot and Peluso 2003:154). Accessibility is then set as a basis to uphold production capacity and build robustness and adaptability in face of a shock. Moreover, it has been shown that even in regions with access to agricultural inputs, a lack of water resources can severely reduce production capacity (Lin 2011). On the other hand, other crops or livestock play a crucial role in diversifying the sources of income and lowering the reliance on tomato sales as a cash-crop, and thus contributing to building farmers' robustness. According to the CLD (Fig. 8), robustness is the ability to balance the strengths of the three identified feedback loops, by adjusting the input use or the farm revenue. More concretely, a diversified source of income from other crop production in another season would enable farmers to balance the non-profitability of the tomato sale. However, both of the shocks had an effect on the desired outcome, which enhances farmers' livelihood sustainably and that of the farming system, requiring Ghanaian tomato farmers to develop adaptability.

Adaptability

The survey results show a wide variety of agronomic practices used by farmers to respond to the shock. The most widely used involve changing the timing of planting, crop diversification, water harvesting, practices that were also observed in other studies and that rely mostly on farmers' willingness to implement these changes. Contrary to other studies, our results show that off-farm migration has not been suggested by the farmers (Tambo 2016, Antwi-Agyei et al. 2018, Kumasi et al. 2019). On the one hand, the lack of accessibility, described above, constitutes a barrier to effective implementation of climate adaptations measures (Antwi-Agyei et al. 2015). On the other hand, the adoption of such practices should also be linked to market and policy challenges, to enable farmers to receive their expected tomato price, after a season of high climate variabilities (Attoh et al. 2014). As a matter of fact, multiple barriers for smallholder integration into markets have been identified, such as a lack of

Fig. 8. Causal loop diagram of the tomato production system.



access to information and technology, poor financial services, and inability to meet standards of more formalized markets (Kuhl 2018). As our CLD shows, the combination of farmers' increasing inputs expenses in order to adapt to heavy rainfalls and low market prices caused by global trade doubly affect farmers at the end of a season.

Adaptation practices can have the particularity to keep the same structures and feedback mechanisms within the farming system, such as increasing the use of inorganic pesticides for a given time period to minimize the effects of a pest. This can be problematic when these are not benefiting or even harming actors/farmers. Thus, few of those practices enable a change in the structure nor the feedbacks mechanisms that sometimes put farmers in a more vulnerable situation and prevent farmers from being drawn out from the dynamics of the system. For that reason, a third component of resilience building is required, transformability.

Transformability

Transformability is seen as the capacity to significantly change the internal structure and feedback mechanisms in response to a shock. The change foreseen in the transformation could refer to a radical change that would challenge prevailing norms and interests, and learn to deal differently with climate change adaptation (O'Brien 2012, Termeer et al. 2016). An emphasis on transformability implies extending the focus in social-ecological research to new forms of governance in the systems (Dietz 2003, Folke et al. 2010).

DISCUSSION

Here, we focus on exploring potential ways of enhancing tomato farmers' resilience by having a look at possible structural changes, first through policy changes and second through tomato value chain stakeholders' interactions.

Enabling transformation through market options for tomatoes

An important finding from this study is the high exposure of farmers to market related shock and their inability to develop proper mechanisms to adapt to low tomato prices (Fig. 7). Fresh tomatoes are highly perishable, which gives farmers little room for flexibility when it comes to selling them at the market. As a horticultural crop, tomatoes require adequate infrastructures and steady reliable markets (Britwum 2013). When these conditions are not met, it results in important post-harvest losses due to poor quality of roads and insufficient/nonexistent infrastructures (Adimabuno 2010, Kolavalli 2019). For this purpose and given the central role of tomato in Ghanaian cuisine, various options are possible and have been explored like drying them (Owureku-Asare et al. 2017) or making tomato paste (Frimpong Boamah and Sumberg 2019). These measures would enable the stabilizing of the balancing loop B in our CLD and better secure the revenue from tomato production.

However, the importation of fresh tomato from Burkina Faso and the availability of cheap tomato paste from Italy and China have continuously increased in the last decades (Frimpong Boamah and Sumberg 2019). This international trading leads to uncompetitive prices that have been recognized as signals of market failure for Ghana's tomato marketing system (Amikuzuno and von Cramon-Taubadel 2012). To this extent, Ghana's dependence on imported tomato paste was used in international advocacy efforts to illustrate the unfairness of international trading agreements and the need to change Ghana government policy (Frimpong Boamah and Sumberg 2019). Alternatively,

other processing methods, such as drying of fresh, ripe tomatoes into dried tomato products, needs to be explored to extend the shelf life as well as add value to the crop (Owureku-Asare et al. 2017). Altogether, the transformation of the tomato marketing system, through alternative forms of valorization, should be reached with the active participation of other stakeholders from the value chains.

Enabling transformation through stakeholder engagement

The spectrum of adaptation options revealed in this study mostly involve farmers within their farms. However, active and dynamic exchanges between stakeholders of the tomato value chain have been reported in the interviews conducted. Statements by the interviewees (Table 4) show how input suppliers play the role of credit loaner, or how traders sell tomatoes of the UER in Kumasi. Thus, farmers do directly interact with many other stakeholders, from input suppliers to traders and agricultural extension officers. The horticulture market in Ghana is characterized by an informal "two-level" marketing system, meaning that the traders are the direct link between farmers and consumers (Robinson and Kolavalli 2010a). Tomato traders constitute a network of women, called "market queens," who exercise a certain level of control over the supply of the commodity and the price fixation (Adimabuno 2010). Because transformation can be understood as "shifts in perception and meaning, social network configurations, patterns of interactions among actors including leadership and political and power relations, and associated organizational and institutional arrangements" (Folke et al. 2010), economic interactions and power relations also play a role in enabling the enhancement of resilience. Taking accountability for enhancing resilience becomes not only a farmers' challenge but all the stakeholders of the value chain (Tendall et al. 2015). Thus, the focus on adaptation within the farming system in a lot of resilience studies let some scholars comment that the actual "highly political" stance of resilience promotes the maintenance of the status quo of a potential oppressive system rather than creating opportunities for transformation (Resnick 2019). Yet, the government has not managed to detect and endorse the promotion of specific agro-industrial sectors that would have helped structural transformation (Resnick 2019).

The methodological approach of this research led to limitations and recommendations for further research that will briefly be described here. First, concerning the data collection, evident methodological limits can be mentioned such as the lack of full representation of the farmer sample we surveyed. The selection of the districts and the farmers we interviewed was done with the support of the regional division of the Ministry of Agriculture. For this reason, the selection was not fully random and might have led to some bias. Then, the language and cultural barriers led to another set of limitations in the translation and the interpretation of some interviews, which may have caused us to lose a layer of depth in the consideration of some answers.

In the current context where increasing recognition is given to the need of transforming food systems, we urge the need to add a social sciences lens, through power analysis, to the understanding of food systems' resilience and in particular their transformation. A systemic approach to resilience in food systems should consider power dynamics (Jacobi et al. 2021) because they shed light into the actors benefitting from the shocks as well as actors upholding those who are more heavily affected. As a way to contribute to the shift into a critical resilience approach, we suggest adding to this study a power lens to resilience, exhibiting how power and resilience are intrinsically linked.

CONCLUSION

This study investigated the exposure and response mechanisms of tomato farmers in the face of climate and market variability using evidence from a farmer survey conducted in two regions of Ghana and a series of stakeholder interviews. We found that farmers are particularly exposed to climate shocks, like drought and heavy rainfall, which results in reducing production activities and lowering revenues. In both regions, a set of soil and water management practices have been adopted by farmers as response mechanisms: crop rotation, intercropping, supplementary fertilization, water tanks, or water retention ditches were the most important and common strategies employed in response to the changing climate.

However, these adaptations within the farm did not really enhance the resilience of the farmers. The reason is mostly because of the important role that the currently dysfunctional market plays for tomato farmers, i.e., farmers are highly vulnerable because of current price fixation mechanisms. Farmers remain powerless in face of low prices, leading to a loss of revenue. No adaptation mechanisms, other than agricultural diversification, have been developed yet to face this economic shock.

Thus, enhancing systemic resilience becomes all the more important to face this double exposure. Moreover, the focus on two regions with strong multidimensional differences enables to highlight some of the mechanisms enhancing robustness and adaptation capacity. Whereas in Ashanti a higher access to inputs, services, and market connections serves the producers, the UER appears once again highly exposed and subject to stronger negative impacts in face of both market and climate shocks.

We conclude that the current system is suboptimal and therefore requires transformation: a change in the state of the system that could question the very structure and feedback mechanisms of this system. An integrated and holistic view on resilience is required, involving other stakeholders from the value chain and beyond. The need for a more resilient system, which involves more resilient farmers, must be achieved by taking into account the underlying dynamics and power relationships between the various stakeholders. Climate or market shocks link farmers to their community, at different levels, from the value chain to the locality or the region. Solidarity mechanisms are forms of empowerment (Laube et al. 2012), highlighting the need to cultivate the resilience potential of human interconnections. Identifying drivers of change and supporting the structures through specific agro-food policies, encompassing climate but also trade attributes are much-needed ingredients to lean toward a sustainable and viable transformation of the tomato production system.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/13310

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Data Availability:

The data/code that support the findings of this study are available on request from the corresponding author, KB. None of the data/code are publicly available because they contain information that could compromise the privacy of research participants.

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Appendix 1. Descriptive R code to analyse the data

Please click here to download file 'appendix1.r'.

Appendix 2. Descriptive R code to analyse the data

Please click here to download file 'appendix2.xlsx'.

Appendix A: Interviewees profile

No.	*Type(s) of actor*	*Male/ Female*	*Place*	*Date*
1	Market queens from South, close to the Queen Mother	F	Kumasi central market	22.10.19
2	Seller	F	Navrongo, new marketplace	30.10.19
3	Seller	F	Navrongo, old marketplace	30.10.19
4	Seller	F	Navrongo, side of the road	30.10.19
5	Input supplier/farmer	F	Navrongo, shop	30.10.19
6	Farmer	M	Gia	31.10.19
7	Farmer	M	Saboro	1.11.19
8	Loading boy/ leader/ son of a market queen	M	Paga marketplace	2.11.19
9	Input supplier/ extension and NGO officer/ farmer/ teacher	M	Navrongo, shop	2.11.19
10	Leader of the sellers' association	F	Navrongo, side of the road	3.11.19
11	NGO agent (c.f. VegCenter)	M	Navrongo, Azakka	3.11.19
12	Market queen from UER	F	Paga marketplace	4.11.19
13	Market queen from UER	F	Paga marketplace	4.11.19
14	Charlotte	F	Saboro	5.11.19
15	Input supplier	M	Navrongo, shop	6.11.19
16	Farmer	M	Gia	9.11.19
17	Farmer/ fisherwoman	F	Gia	9.11.19
18	Hired labour	M	Gia	10.11.19
19	Hired labour	M	Gia	10.11.19
20	Loading boy	M	Paga	13.11.19
21	Loading boy	M	Paga	13.11.19
22	Sorter	F	Paga	14.11.19
23	Extension officer	M	Navrongo, extension office	13.11.19
24	ICOUR engineer	M	Navrongo, Azakka	14.11.19
25	Lead boy (leader)	M	Paga (Burkina Faso)	19.11.19
26	Farmer	M	Navrongo	21.11.19
27	MOFA regional director	M	Bolgatanga	28.11.19
28	Market queen	F	Kumasi central market	10.12.19

29	Market queen	F	Kumasi central market	10.12.19
30	Expert (professor)	M	KNUST, Kumasi	10.12.19
31	Director of an input company	M	Accra	16.12.19
32	Union representative of informal workers: including the greater accra tomato traders' association	F	Accra	17.12.19
33	Expert (professor)	F	University of Ghana, Accra	18.12.19

Appendix B: Summary of data collected during the interviews on climate change responses

Grey highlight indicates when there was a misunderstanding with the interviewee about what was a climate shock. Often, at the beginning, I would talk about drought, but they would understand it as their dry season, bringing confusion in the discussion.

INTERVIEW NB	KIND OF ACTORS	RESPONSE TO SHOCK	CREDITS/HELP
1	Market/Mother Queens	During the dry season it is hard to find tomatoes. Sometimes have to wash the seeds and give to the farmers so that they can plant and harvest for them. They give the farmers credits (not only during shocks) and climate shock make the farmers unable to give the money back: they run at losses.	Trader association
2	Seller in Navrongo	There are always tomatoes to buy, no matter what happens. In the dry season, they get tomatoes from Burkina Faso mainly.	Farmers give her on credit sometimes
3	Seller in Navrongo	In the dry season, towards march, they get tomatoes from Burkina Faso	N.D.
4	Seller in Navrongo	Because of the heavy rains, their job is more difficult this year. They are already buying from Burkina Faso, while normally it begins later.	She is part of an association
5	Input supplier/ farmer	In times of shocks, no money because no one farms.	Farmer's association
6	Farmer Gia	He has a mechanized borehole that gives him water the whole year round and thus does not experience "droughts"	N.D.
7	Farmer Saboro	No farming in times of drought because does not have irrigation. Sell animals. Heavy rains of this year affected other farmers but not himself.	Part of an association but does not "work"
8	Loading boy	N.D.	N.D.
9	Input supplier	Heavy rains: in the Tono area, some farmers had to quit farming because they could not get additional seedlings. Drought: in the Tono area, sometimes water table is too low (end of dry season) and ICOUR tells farmers that they need to quit farming but at the time, most have already harvested.	He helps farmers through credits and they always give him back the money
10	Seller in Navrongo	Even in times of droughts, they will always find tomatoes, but it is scarce. Price will get high.	Association
11	NGO agent	After the heavy rains of this year, most farmers planted again, other could not because they did not have seeds anymore.	-

12	Trader from Paga	Droughts/floods: they will always find some tomatoes in Burkina Faso	Association
13	Trader from Paga	When there's drought, they rely more on Burkina Faso	Association
14	Farmer	Heavy rains spoiled her fields this year, she replanted with new seedlings. "We have to take our cost. For that one there, if rain come and spoil your garden or your farm, the cost, you have to take it. No one will pay for it"	Association (women farmers)
15	Input supplier	Difficult for input suppliers because no farming again. For example, in July this year, there was a small drought.	Farmers pay back their loans to him by selling their animals
16	Farmer Gia	Heavy rains or droughts spoil the farming: she manages to still have small production and goes into other business. This year, she does not manage to plant again new seedlings.	No help from traders. No association
17	Farmer Gia	Only farms during the rainy season. If there is too small rain during the rainy season, he goes fetch water from small rivers or dams	No association
18	Hired labour	Cannot work during a climate shock. Thus, goes to school	N.D.
19	Hired labour	Cannot work during a climate shock. Sits at home or goes to school.	N.D.
20	Loading boy	N.D.	N.D.
21	Loading boy	For the moment there is no tomatoes in Burkina Faso: it is not yet on-season,	No
22	Sorter	When there is droughts or heavy rains, there is no work. But in Burkina there is always plenty.	Neighbour's association
23	Extension officer	"that's it, trying to let the farmers know that it [climate shocks] shouldn't be only a challenge but you can/ from some challenges you can get an opportunity out of challenges."	-
24	ICOUR	When water table is too low, they cut down an area.	
25	Lead boy	Droughts never affect Burkina Faso because they have many dams. This year, the heavy rain affected production: the season of Burkinabe tomatoes starts later.	Association. Helps the farmers and the traders.
26	Farmer	In times of drought, stop farming and sell animals. Because of the heavy rains this year, he transplanted 5 times: he managed to buy new seeds by selling animals.	Association with other farmers of the area
27	Regional MOFA	MOFA distributes seeds when there are climate shocks, in order to help farmers.	-
28	Trader from South	There are always tomatoes in Burkina Faso. Nothing affects their production.	Traders' association
29	Trader from South	Sometimes (end of season) there are less tomatoes in Burkina. In these cases, they can drive to Mali to go find tomatoes.	Traders' association
32	Union worker	When they struggle with tomatoes here in Ghana, there is always some in Burkina Faso.	-
33	Expert	Farmers are helping each other's in difficult times	

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