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Diversity in perception and management of farming risks in southern Mali

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ABSTRACT

A deeper understanding of how smallholder farmers perceive and manage risks is crucial to identify options that increase farmers' adaptive capacity. We investigated a broad range of risks that play a role in farmers' decision-making processes. In the cotton zone of Mali opportunities and constraints vary with the resource endowment of farms. Furthermore, as households are large in this region, often comprising 20–50 family members, intra-household diversity may influence perceptions and risk management. For this reason, we analysed diversity both among and within farms. Information was gathered through focus group discussions and a survey with 250 people from 58 households. Risk was assessed as the combination of the perceived frequency of occurrence of hazards and the impact on food availability and income. Farmers faced a diversity of risks, with hazards related to animal and personal health, and climate variability of highest concern. Resource endowment of farms was related to risk perception to a limited extent. Differences within the household were related to the generational factor and decision power, and not to gender. Household members with decision power worried most about risks. Almost a quarter of described hazards occurred with a high frequency and led to a high impact on food availability and income. Low resource-endowed farms were more often exposed to high risks than other farm types. Farmers applied a variety of actions to cope with hazards, yet in many cases farmers lacked a response. Medical actions were targeted to human and animal health hazards. Changes in field and animal management practices, adapted consumption rates and calls on social interactions, were combined for a diversity of hazards. By assessing the diversity of risks encountered by farmers and the diversity of risk management actions taken by farmers, this study goes beyond common risk research that focuses on a single hazard. Our results suggest that development interventions should not focus on either agronomic or economic options separately, but combine both to strengthen social well-being and agricultural production.

1. Introduction

Smallholder farmers in West Africa face many risks. Climate variability is a well-known source of risk that is expected to increase due to climate change (e.g. Akumaga and Tarhule, 2018; Schmitt Olabisi et al., 2018; Tiepolo et al., 2018). However, the agricultural risks that farmers face are not only related to the weather. Risks represent the negative impact of a hazard and the frequency with which a hazard occurs. Both elements are associated with uncertainty, resulting in difficulties for farmers to manage risk. Hazards are diverse and can be related to biophysical as well as to marketing, financial, legal and human resources (Baquet et al., 1997). For example, drought, pest attacks and variable prices impair West African farmers' production and income (e.g. Aune and Bationo, 2008; Schlecht et al., 2006).

Agriculture in West Africa is additionally under pressure due to population growth, urbanisation and declining natural resources. To break the current trend of stagnating yields (Falconnier et al., 2015; Tittonell and Giller, 2013), agricultural technologies and farm management changes are needed to increase production and income in a sustainable way. To increase the probability of adoption, these options should be tailored to the local context, and take into account farmers' decision making processes (Descheemaeker et al., 2019; Giller et al., 2011). Understanding farmers' perceptions of and attitude toward risks and coping strategies is important in this tailoring process (Douxchamps et al., 2016; Kisaka-Lwayo and Obi, 2012; Schlecht et al., 2006), as they determine how farmers deal with uncertainty. Both perception and attitude are dynamic and can be influenced by a plethora of personal and social factors such as culture, beliefs, habits,

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personality, past experiences and motivation (van Winsen et al., 2011). Building on farmers' current practices in dealing with uncertainty is crucial to identify options that increase farmers' adaptive capacity (Cooper et al., 2008; Milgroom and Giller, 2013).

Risk management can be divided into reactive management (ex-post, after the event has taken place) and preventive management (ex-ante, before the event takes place). Besides this division, Schaper et al. (2010) distinguish possible strategies as risk avoidance, risk reduction, risk transfer or risk acceptance. Risk avoidance relates to the exclusion of practices that are prone to a risk, thereby limiting the exposure. Risk reduction covers diminution of the farm's sensitivity to hazards, or occurrence probability of the hazard. The consequences of a farming risk can also be transferred to others, for example through insurances or long-term contracts with price guarantees. Risk acceptance (i.e. to do nothing) is the last option for farmers. Some examples of risk management practices that farmers in sub-Saharan Africa implement are (i) generating income from off-farm sources (Douxchamps et al., 2016; Wichern, 2019), (ii) adapting or spreading planting dates (Milgroom and Giller, 2013; Traore et al., 2014), (iii) maintaining crop diversity (Frison et al., 2011), (iv) keeping livestock (Valbuena et al., 2015), (v) having fields for shared and individual production within a household (Guirkinger and Platteau, 2014) or (vi) reducing food consumption (Wichern, 2019).

Within a single smallholder farming system, farms vary enormously in available resources, the capacity to invest, the constraints that are faced and the objectives farmers set. A farm typology based on resource endowment is often used to understand this farm diversity (e.g. Alvarez et al., 2018; Falconnier et al., 2015). The resource endowment of the farm may not only define the production strategy, but also the perception of which hazards are relevant, their impact and the risk management strategies that are feasible. Hence, poor farmers are likely to be more risk averse (Kisaka-Lwayo and Obi, 2012). The relation between risk perception and management on the one hand and socio-economic farm characteristics on the other hand is described in the literature (e.g. Asravor, 2018; Mubaya and Mafongoya, 2016; Tarfa et al., 2019). However, this diversity among households has not been explored through the use of farm types for West African farming systems. Additionally, apart from inter-household variability, also intra-household variability may influence risk perceptions and attitudes. Malian households are often large entities extending both vertically and horizontally (Guirkinger and Platteau, 2014). Vertical extension refers to sons continuing to live with their parents after marriage, while horizontal extension means that the brothers of the household head together with their wives and children also form part of the household. Most decision power lays with the household head, who is usually the eldest man in the household, accompanied by a head of labour (Kanté, 2001). Within such large households, access to resources, interests, constraints and opportunities differ between household members (Droy et al., 2012; Guirkinger and Platteau, 2015; Paresys et al., 2018). Michalscheck et al. (2018) advocate to analyse diversity at the level of individual farmers to understand the perception and impact of agricultural technologies and suggest people should be differentiated in terms of decision-power (the household head versus other household members), gender and generation. Intra-household variability is usually not accounted for in agricultural risk assessments, with the exception of a few studies differentiating gender groups (Mishra and Pede, 2017; Rao et al., 2020).

We focus our research on the cotton region of southern Mali, an important agricultural zone in Mali both for cash generation and food production. Farmers are generally food self-sufficient but remain poor and lack a nutritious diet (Falconnier et al., 2018). In this area farmers and researchers have jointly participated in co-learning cycles since 2012 to tailor options to the farming context (Falconnier et al., 2017). Existing agricultural hazards are variable rainfall, volatile commodity prices, moments of insufficient labour, agricultural pests and diseases, and human diseases affecting family members (Van Dijk et al., 2004). It is not known how farmers perceive the risks associated with these hazards and what management strategies they apply or have access to.

In the West African context agricultural risk studies often focus on a single commodity or one source of risk, such as climate change and variability (Komarek et al., 2020), with exceptions like Asravor (2018) who examined the major sources of risk in Northern Ghana through farmers' perception and management strategies. In our research we broaden the scope to the system level and include all possible risks perceived to be influencing overall farm production and livelihood of diverse farms and household members. Our participatory risk assessment expands the approach of the World Bank (2016) and Kisaka-Lwayo and Obi (2012) with the inclusion of intra-household diversity and in-depth interviews. The first objective of this study is to analyse which risks farmers perceive to be important and how this perception differs between and within households. Secondly, we assess how farmers manage their farm in a risky environment. Through this research, we aim to answer the following questions. (i) What hazards do farmers perceive within the agricultural system? (ii) What are their perceptions of the frequency and severity of those hazards? (iii) How does risk perception differ among farms with different resource endowment and between different household members? (iv) How do farmers prepare for and react to hazards? We hypothesize that both the risk perception and the related coping strategies depend on farm resource endowment and hence differ among farm types. A second hypothesis is that different household members have a different risk perception, related to the responsibilities they hold within the household.

2. Materials and methods

2.1. Conceptual framework

Agricultural risk has been described in many ways in the scientific literature. Brooks (2003) highlights a main difference in the interpretation of risk as "the probability of a certain hazard taking place", referring to the event itself, versus" the probability of reaching a certain outcome", referring to the combination of event and possible impact. The latter is followed by the IPCC Working Group II (2001), Jones et al. (2003) and the World Bank (2016). Here we follow the World Bank definition of agricultural risk: "Agricultural risk is a combination of the likelihood of a hazardous event or exposure(s) (to the hazard) and the severity of the losses that can be caused by the event or exposure(s)". First, we used farmers' perception of the frequency of a hazard as a proxy for the likelihood of the hazard happening. Secondly, we described the severity of losses by the perceived impact on farm food availability and income (Fig. 1). These two indicators for loss were chosen because food self-sufficiency and income are important objectives of farmers, and because they are relevant in the policy debate on poverty reduction (Ollenburger et al., 2019).

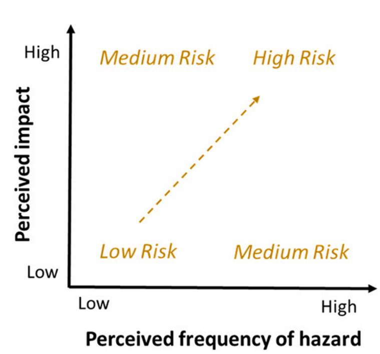

Fig. 1. Graphical representation of the different factors determining risk. After Vose (2008) and Ratliff and Hanks (1992).

A certain level of uncertainty –either in probability of the hazard or in the possible outcome– is an essential aspect of risk (PARM, 2014) and it limits effective planning. The concept of uncertainty can be further disentangled into a probability (a known likelihood) and a real uncertainty (not-knowing). Not-knowing can refer to something an individual is unaware of but knowable, or to something that is generally unknowable. In our case, we consider all three forms of uncertainty in our assessment of perceived hazards.

The term hazard refers to the triggering event that may cause a loss. Hazard is often used to describe biophysical events such as droughts, floods or storms (Brooks, 2003), but can also refer to shocks in the social or economic domain. The uncertainty aspect distinguishes a hazard from a constraint. Constraints are existing "conditions that lead to suboptimal performance" (World Bank, 2016). Trends are different from hazards since they display a longer-term structural pattern of change (World Bank, 2016) and are therefore more predictable. Constraints and trends were not subject of this research.

This theoretical framework was operationalised by first evaluating farmers' concerns, without pre-defining the type of hazards. We asked farmers to identify all the possible shocks they could be susceptible to. This implies that both catastrophic risks and risks with lower impact but higher frequency were included. Next, the most important risks were quantified by assessing farmers' perceived frequency and perceived impact of the hazards on food availability and income. Finally, farmers described both their reactive and preventive management options for these hazards.

2.2. Study area

The study was carried out in four villages in Koutiala district, situated in the Sudanian agro-ecological zone in southern Mali. The nearby N'Tarla research station recorded an average rainfall of 850 mm/year with a high variability ranging between 500 and 1200 mm/year in the period 1965–2005 (Traore et al., 2013). This rainfall pattern is unimodal and extends from May until October. Temperatures range between a mean annual minimum of 19.2 °C and maximum of 35.7 °C. Soils are mainly Lixisols (FAO, 2006). Two of the villages, Deresso and N'Tiesso (12°31′31"N, 5°20′20"W, elevation 340 m), were located at a distance of 15–20 km north of the city of Koutiala, near the main tarred road. Two other villages, Nampossela and M'Peresso (12°19′00"N, 5°32′30"W, elevation 350 m) were at a similar distance south of the city with poor access roads.

The region is known as the "old-cotton basin of Mali" that benefitted from the cotton boom in the 1980s and 1990s (Van Dijk et al., 2004). The cotton production is supported by the partly state-controlled CMDT (Compagnie Malienne pour le Développement des Textiles) which sets a fixed price at the beginning of the season, secures and organises collection of the harvest, and provides access to subsidised fertiliser (Droy et al., 2012). Farmers' first objective is to produce enough food for the household with the cultivation of maize, millet and sorghum (Bosma et al., 1999; Falconnier et al., 2015; Kanté, 2001). Agricultural activities are the main source of income for households (Losch et al., 2012), which is generated mostly with the cultivation of cotton and maize. Both mineral and organic fertiliser are principally targeted to these two crops. Livestock plays an important role in the system providing draught power, manure and cash because animals are often sold in times of need (Kanté, 2001; Van Dijk et al., 2004). Only a quarter of farms achieve both food self-sufficiency and an income above the poverty line (1.9 $PPP/day/person) (Falconnier et al., 2018).

The population is mainly Minianka, with presence of other ethnic groups as the Fulbe, Dogon or Bambara (Jonckers, 1981; Van Dijk et al., 2004). Population density reaches 70 people km^{-2}, which is high compared to the rest of the country (Soumaré et al., 2008). Almost all land suitable for agriculture in this area is cultivated, indicating pressure on (communal grazing) land (Benjaminsen, 2002; Soumaré et al., 2008; Van Dijk et al., 2004). Because of this pressure, some livestock that is not needed for animal traction or milk production is moved to grazing areas outside the village territory during the rainy season to avoid crop damage on fields (Sanogo, 2010; Turner et al., 2014). Nevertheless, most cattle are grazed year-round on communal rangelands during the day and kept in corrals overnight. During the dry season, livestock grazes on the crop residues in the field (de Ridder et al., 2015).

Diversity between households is captured by a farm type classification developed by Falconnier et al. (2015) based on resource endowment. The number of livestock, the area cultivated, the size of the household and the number of draught tools (ploughs, weeders and sowing machines) are the farm components that define the type (Table S1). The four farm types are High Resource Endowed farms with a Large Herd (HRE-LH), High Resource Endowed (HRE), Medium Resource Endowed (MRE), and Low Resource Endowed (LRE) farms.

2.3. Focus group discussions

A first round of focus group discussions (FGD) was organised during the rainy season of 2017 in four villages (Nitabougoro, Nampossela, Deresso and N'Tiesso). One session per village was organised at which men, women and youth from the four farm types were invited. Each session lasted around two hours and attracted between seven to 24 participants. The main goal was to list the spectrum of agricultural risks farmers feel they are facing, by asking them about events that are a source of risk. The question to farmers was framed as follows: "What are the events related to agricultural activities (crop and livestock) that might happen before, during and after the growing season, and that you worry about because it might result in a loss?". The concept of risk was translated to the Bambara word "farati", which means "danger". In communication with farmers, the aspects of uncertainty of events and possible negative outcome were emphasized. This exercise led to a list of 24 hazards that was the basis for the individual survey on risk perception. Farmers categorized the hazards according to the timing (start, during, or end of the rainy season) when the hazard is likely to cause the biggest impact on farm production and income. The category "Other" was given to hazards without a clear time component.

After the individual surveys, experts on specific topics were consulted and a second cycle of FGDs was held in Nampossela, N'Tiesso and Deresso in 2018, attracting four to five participants each. This round of information gathering was organised to complement the first analysis of perceived risks. For example, after it became clear that health issues of people and animals were of high importance, the local health centres and a veterinarian were contacted to give more insight on the incidence of common diseases. For the second cycle of FGDs, the aim was to gain insight in how risks and coping strategies are expressed at village level. For instance, farmers' health influences labour availability. To understand the possibilities of mechanisation as a solution, it was asked how many tractors are present in the village. For understanding access and quality of inputs, the different access points in the village were discussed. In N'Tiesso, one extra FGD was held inviting only women ($n = 4$), discussing the topics that appeared of more interest to them, e.g. market activities. Since the objective was to collect specific and additional information, small groups with key informants sufficed.

2.4. Individual surveys on risk perception

A total of 250 members from 58 households participated in an individual survey assessing risk perception in 2018. The households were selected based on availability, willingness and farm typology. The distribution of the farm types included in the survey is similar as the overall distribution for the Koutiala district described in Falconnier et al. (2015), i.e. 16% HRE-LH, 34% HRE, 40% MRE and 10% LRE (Table S1). For every household, minimum three and maximum seven different family members were interviewed. These individuals were selected randomly from the members that were present at the time of surveying, but at least included a decision maker (the household head or the head of labour), another male or female household member and a young person between 15 and 25 years old (United Nations, 1995). Another condition was that the household member should live on the farm and participate in farm activities for at least three months a year. The surveys were conducted in isolation from other family members to reduce influence on the answers.

The age of respondents varied between 15 and 97 years of age. The average age of youth ($n = 49$) was 17 years, that of other farmers ($n = 117$) 33 years, while decision makers ($n = 67$) were 49 years old on average.

Respondents ranked the five most important hazards from the list defined in the FGD's. During this survey they also gave a score (Likert-type item) expressing their concern for the related risk (0 =" no", 1 =" little", 2 =" medium", 3 =" high" concern). They were free to include additional hazards if they felt the list was not complete.

2.5. Semi-structured interviews on hazard impact and frequency, and risk management strategies

Risk impact and frequency as well as the related risk management practices were assessed through a semi-structured interview with one single person of the household that holds decision power, be it the household head or the head of labour ($n = 58$). Invariably, this was a man. The average age of the subgroup of decision makers was 46 years of age and ranged from 24 to 70 years of age. The youngest household head was not classified as youth because of the role of decision maker he took in the household.

While perception of risk is individual, the management of risks is largely executed at farm level. Most fields are family fields, and also livestock management is generally organised centrally. Decision making processes in such large households are complex, and all household members have some influence (Michalscheck, 2019). However, the majority of decisions is taken, or at least supported, by the decision maker (household head or head of labour) (Kanté, 2001). Therefore, farm risk management strategies were assessed by interviewing a single decision maker.

For the three hazards the decision maker ranked as most important, he was asked to assess the risk for the last time the hazard took place. This was done by scoring the perceived impact at farm level and the frequency of this hazard taking place. Out of the 24 hazards, 20 were ranked in the top three risks of a decision maker during this exercise. First, farmers indicated the frequency of the hazard as follows: improbable (every 40 years), isolated (every 20 years), occasional (every ten years), probable (every five years), very probable (more or less every three years), every year, and several times a year (World Bank, 2016). Secondly, farmers scored the impact at farm level by answering the questions: "what were the losses at farm level related to food?" and "what were the losses at farm level related to income?" Impact scores are ranked going from none or negligible (losses < 5%), moderate (losses 5–15%), considerable (losses 15–50%), to catastrophic (losses > 50%) (World Bank, 2016). Specifying losses for every impact level ensures that every level has a similar meaning for every farmer. As the estimation of an exact proportion of loss is challenging for farmers, this method allowed to categorize impact, rather than to quantify it.

To assess farmer risk management, respondents were encouraged to tell the story of what happened on their farm the last time the hazard took place. By so doing we avoided hypothetical questions such as "how would your farm be affected if?" and "how would you react if?" (Azevedo et al., 2000). First, farmers described how the hazard impacted the different components of the farm (crops, livestock, farming activities) in the past. Afterwards, the respondents expanded on how they minimized losses when or after the event took place (ex-post, or reactive action). Finally, they added detail on what they are now doing to prevent losses, knowing that there is a likelihood that the hazard will strike again (ex-ante, preventive action). These preventive actions describe farmers' current management in anticipation of hazards and give insight on how farmers deal with uncertainty. In three cases the farmer did not finalise the questions, so in total 171 hazardous events were recorded.

2.6. Data analysis

2.6.1. Overall perception of hazards: Analysis of ranks and scores

Out of the list of 24 hazards, all respondents ranked their five most important. The most important one was given five points, and the fifth hazard one point. For each hazard, the points given by every respondent were summed and a percentage out of the maximum score (i.e. five points times 250 respondents) was calculated.

The Likert-type scores for the concern of farmers were analysed as ordinal data (Jamieson, 2004) to assess the perception of the risk related to each hazard. Plots are constructed using the "likert" package in R. The perception was compared between both inter-household groups (farm types) and intra-household groups (gender, position in the household). First, the overall comparison of perception between groups was made for the hazards collectively. When comparing two groups, we used the Wilcoxon test, whereas for more groups the Kruskal-Wallis test was applied. The statistical test was performed simultaneously for the 24 hazards, so an adjustment of the alpha value was made using a Bonferroni correction to reduce the family wise error rate (i.e. the desired alpha value is divided by the number of hypotheses; $\alpha = 0{,}05/24 = 0{,}002$). Secondly, if a difference in perception was established, the pairwise Wilcoxon test was used to determine which groups differed. This step included a Benjamini and Hochberg (1995) correction for multiple group testing to control for the false discovery rate. As no women held the position of household head or head of labour, the comparison between women and men excluded the men with decision power. Finally, the exercise was repeated for all hazards individually.

2.6.2. Impact and frequency of hazards define risk

The assessed impact on food availability and farm income was plotted against the frequency of the event happening, in line with the conceptual framework (Fig. 1).

When hazards happened every ten years or less (occasional, isolated or improbable) and had relatively little impact (negligible or moderate), the risk was considered low. If hazards occurred every five years or more often (probable, very probable, every year or several times a year) and at the same time implied a high impact (considerable or catastrophic), the risk was high. Other combinations of frequency and impact were categorized as medium risk.

2.6.3. Strategies applied

Actions in response or anticipation of risks were categorized according to the farm component where changes occur (Table 1). Farmers were asked to describe the actions they were already applying, yet in some cases farmers described their intentions for preventive management. This minority of cases was also included in the analysis. The links between the actions applied and the hazards they are related to were visualised in a heatmap (ggplot package, R). The categorisation of management actions according to timing (reactive and preventive action) and resources used (farm component) is an intermediate step to link farmers actions to the different risk management strategies according to Schaper et al. (2010) (risk acceptance, risk reduction, risk transfer and risk avoidance). Risk reduction as a reaction to a hazard (ex-post) attempts to reduce the impact of the hazard. When applied as a preventive strategy, it can attempt to reduce of the impact but also the frequency of the hazard.

Table 1
Farm component categories used for the different risk management actions mentioned by farmers.

Farm component	Explanation	Farming domain	Level
Nothing	No action	NA	NA
Field	A change in the field management	Agronomic	Field
Input	A change in type, quantity and allocation of inputs	Agronomic	Farm
Crop	A change in area allocated to different crops	Agronomic	Farm
Animal	A change in animal and herd management	Animal husbandry	Animal + Farm
Consumption	A change in planned consumption and sales rates of food products	Socio-economic	Farm
Social	Farmers calling on formal and informal social networks and institutions	Socio-economic	Community
Labour	A change in family and external labour division and agreements	Socio-economic	Farm
Medical	Modern or traditional medical treatment of people or animals	Socio-economic + animal husbandry	Individual/Animal + Farm
Other	Actions that do not fit in one of the categories above	NA	NA

NA = not applicable.

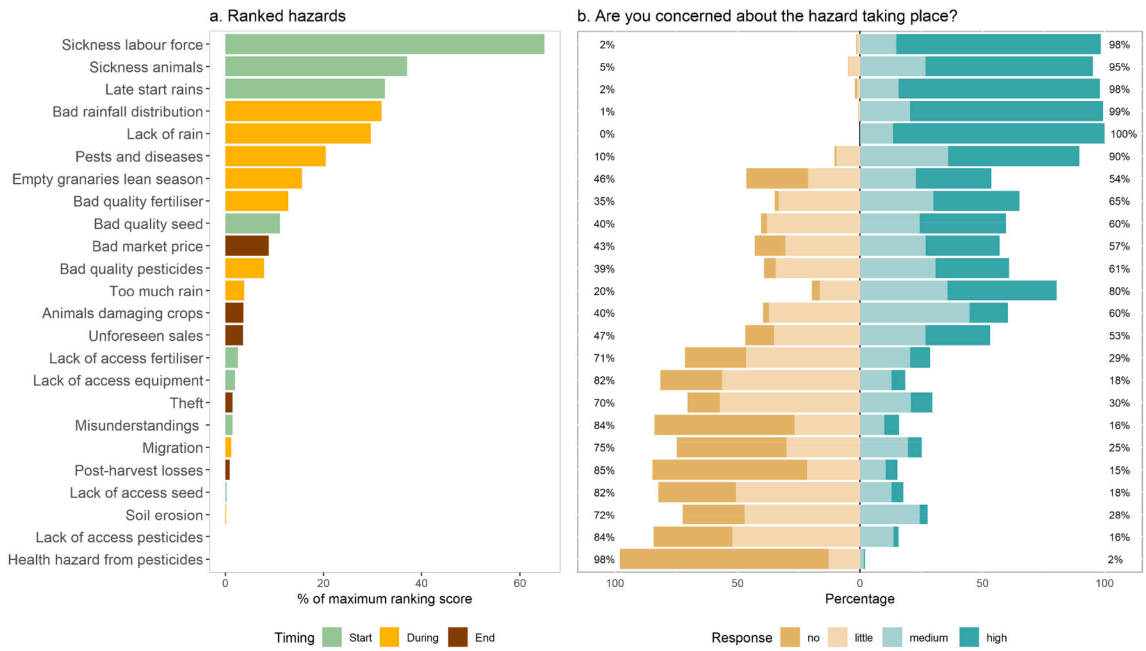

Fig. 2. (a) The 24 hazards that farmers worried most about during the focus group discussions, ranked according to importance given by farmers in surveys (expressed as the percentage of the actual score out of the maximum score of a hazard if all farmers would score it as most important). The colouring represents the timing in the growing season when the hazard is most likely to occur. (b) The proportion of respondents answering “high”, “medium”, “little” or “no” to the question “Are you concerned about the hazard taking place?”. The percentage on the left side is the combined % for “no” and “little”, and the one of the right side for “medium” and “high”.

3. Results

3.1. Important hazards

The focus group discussions yielded a list of 24 diverse hazards farmers deemed important (Fig. 2a and Table S2). These hazards were associated with rainfall patterns or other environmental conditions, access and quality of inputs and equipment, the market, and social and human resources.

The most important risks were related to labour availability and weather hazards occurring at the beginning of the growing season. Family members falling ill was the major concern. Local health care services explained that malaria was the primary cause of illness. Farmers' ranking scores for this hazard added up to 65% of the maximum score, while the remaining hazards scored far less (Fig. 2a). Cattle suffering from illness was the second ranked hazard, at 37% of the maximum score. Animal morbidity is related to the lack of feed during the dry season, which weakens the animals, and the incidence of diseases, such as foot and mouth disease in 2018 (personal communication local veterinarian, Mr. Toure). As cattle are highly valued for draught power, sick animals mainly affected land preparation and weeding, while reduced labour of household members affected weeding and harvesting (Fig. S2). The top five of most important hazards was completed with different climate-related hazards that tended to affect all crops. Rains starting late, poor rainfall distribution, or insufficient annual rainfall amount all scored around 30% of the maximum. Almost all farmers (95–100%) were medium to highly concerned about the top-five hazards related to sickness and rainfall (Fig. 2b).

Farmers also worried about the incidence of crop pests and diseases (20% of the maximum score), and the exhaustion of the granaries during the lean season (16%). Next, farmers ranked a group of hazards related to poor quality of inputs (fertiliser (13%), seeds (11%) and pesticides (8%)). Bad quality of pesticides affected cotton production, whereas bad quality of fertilisers affected mostly maize and cotton (Fig. S2). According to some of the household heads they received fertiliser of poor quality in 2013 and 2014.

Market risks (bad market prices, and no timely access of inputs) were perceived as relatively less important (all less than 10% of the maximum score). The hazard “bad market price” can refer to both selling and buying prices. The social hazards (theft, migration and misunderstandings between household members) scored low. The specific health hazard from using pesticides was perceived least important.

Fig. 3. Proportion of answers on the Likert-type scale given by farmers when asked for their concern, grouped by farm types: High Resource Endowed farms with Large Herds or HRE-LH ($n = 45$), High Resource Endowed farms or HRE ($n = 90$), Medium Resource Endowed farms or MRE ($n = 96$) and Low Resource Endowed farms or LRE ($n = 19$) (farm types with the same letter do not differ significantly ($P < .05$)). (a) All hazards grouped together, (b) individual hazards with significantly different perception between farm types.

Overall, the hazards occurring at the end of the rainy season were perceived less important compared to those happening at the beginning or during the season. For the bottom ten ranked hazards, more than 50% of farmers are not worried (no or little concern) about the possible impact on their farm.

3.2. Perception of risks by different groups of farmers

The overall risk perception differed between farm types ($P = 8e^{-6}$) (Fig. 3-a). LRE and HRE households had a stronger concern than MRE and HRE-LH, although the differences are small. For six out of 24 hazards there was a significant difference in risk perception (Fig. 3-b). The farms with a large herd (HRE-LH) had a significantly lower concern than the high resource endowed without a large herd (HRE) for agricultural pests and diseases, bad quality fertiliser, and post-harvest losses. The HRE-LH also showed least concern of exhausting their granaries during the lean season compared to other farm types; the LRE worried most about this happening. The higher resource endowed farmers (HRE-LH and HRE) showed greater concern than the lower resource endowed farmers for social hazards, such as misunderstandings among household members, as well as migration of household members. Nevertheless, the general concern was low for these social hazards.

In general, men and women had a similar risk concern ($P = .5$) (Fig. 4-a). However, for two hazards, the concern differed significantly (Fig. 4-b). More women than men were strongly concerned about unfavourable market prices ($P = 3e^{-5}$) and the occurrence of unforeseen sales of farm products during the year ($P = .009$). Farmers turn to sell farm products which were foreseen for consumption, when they are in a sudden need for cash without having the financial reserves, for example

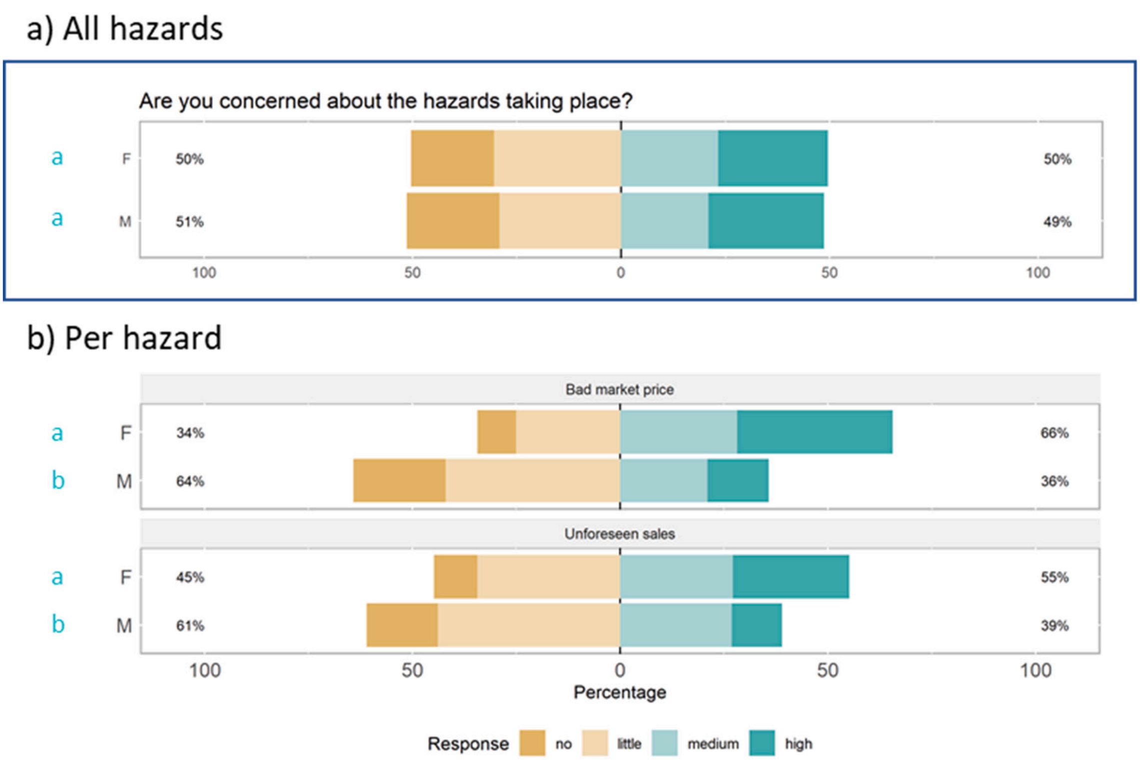

Fig. 4. Proportion of answers on the Likert-type scale given by farmers when asked for their concern grouped by gender (M: male (n = 82) and F: female (n = 96)). Gender groups with the same letter do not differ significantly ($P < .05$). (a) All hazards grouped together, (b) the individual hazards where perception was significantly different between genders.

for contributing in weddings or funerals.

The risk perception differed between farmers with different positions in the household ($P = 2e^{-16}$) for all hazards together (Fig. 5). In general, the person with most decision power (household head or head of labour) was most concerned about all hazards taking place. Youth showed less concern. For every hazard individually, similar differences in concerns were detected. Only the hazards "health issues due to a high use of pesticides", "pest and diseases", and "theft" were perceived equally by the different groups.

3.3. Impact and frequency of hazard defined risk

The perceived impacts and frequencies were plotted in Fig. 6 to assess the perceived risk following the conceptual framework (Fig. 1). The hazard frequencies ranged from occurring in isolation to happening annually. Farmers of all types described this diversity in frequency, except the LRE farmers, who did not report annual or isolated frequencies. Farmers remembered cases from up to 18 years ago (Fig. S1).

The impact of the hazards ranged from negligible to catastrophic, but many times remained negligible or moderate. LRE, and to a lesser extent MRE farmers, described more cases with a catastrophic impact than the other farm types. In general, the losses on income were perceived larger than the losses on food availability. The impacted crops were mainly cotton, followed by maize and sorghum (Fig. S2). In terms of farm activities, the hazards mainly impaired weeding, sowing and harvesting. Cattle was only affected in the case of the specific animal-related hazards as "livestock falling sick", and "lack of access to animal feed" (Fig. S2).

Almost a quarter of the hazards carried a high risk for income (40 cases out of 171), while 11% of the hazards resulted in a high risk for food availability (Table S3). Most hazards bore a medium risk (68% and 78% of the described cases for food and income risk respectively). Low risks were observed in 8% of described cases for both income and food. All farm types were susceptible to risk, but the group of LRE farms was exposed to a high income risk in 44% of the described cases compared to 20–26% for the other farm types. The risk of lack of food was high in

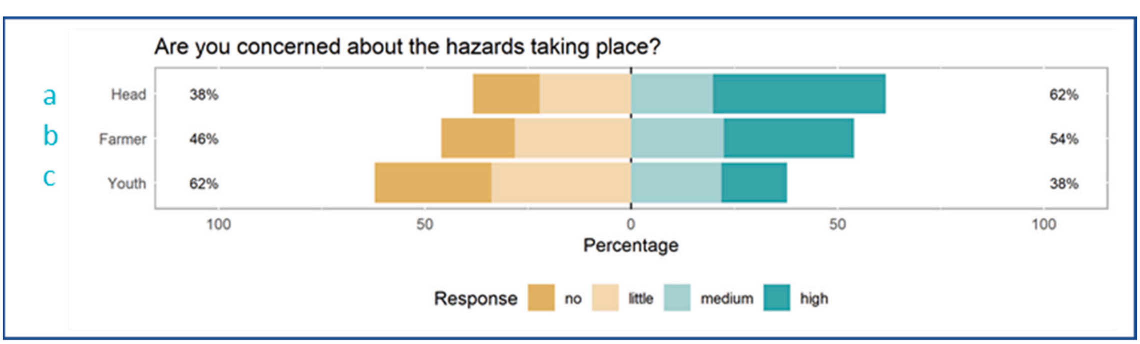

Fig. 5. Proportion of answers on the Likert-type scale given by farmers when asked for their concern, for all hazards together, grouped by position in the household (positions with the same letter do not differ significantly ($P < .05$)). "Head" includes the head of the household and the responsible for labour (n = 72), "Farmer" includes male and female farmers (n = 125), and "youth" includes members between 15 and 25 years old (n = 53).

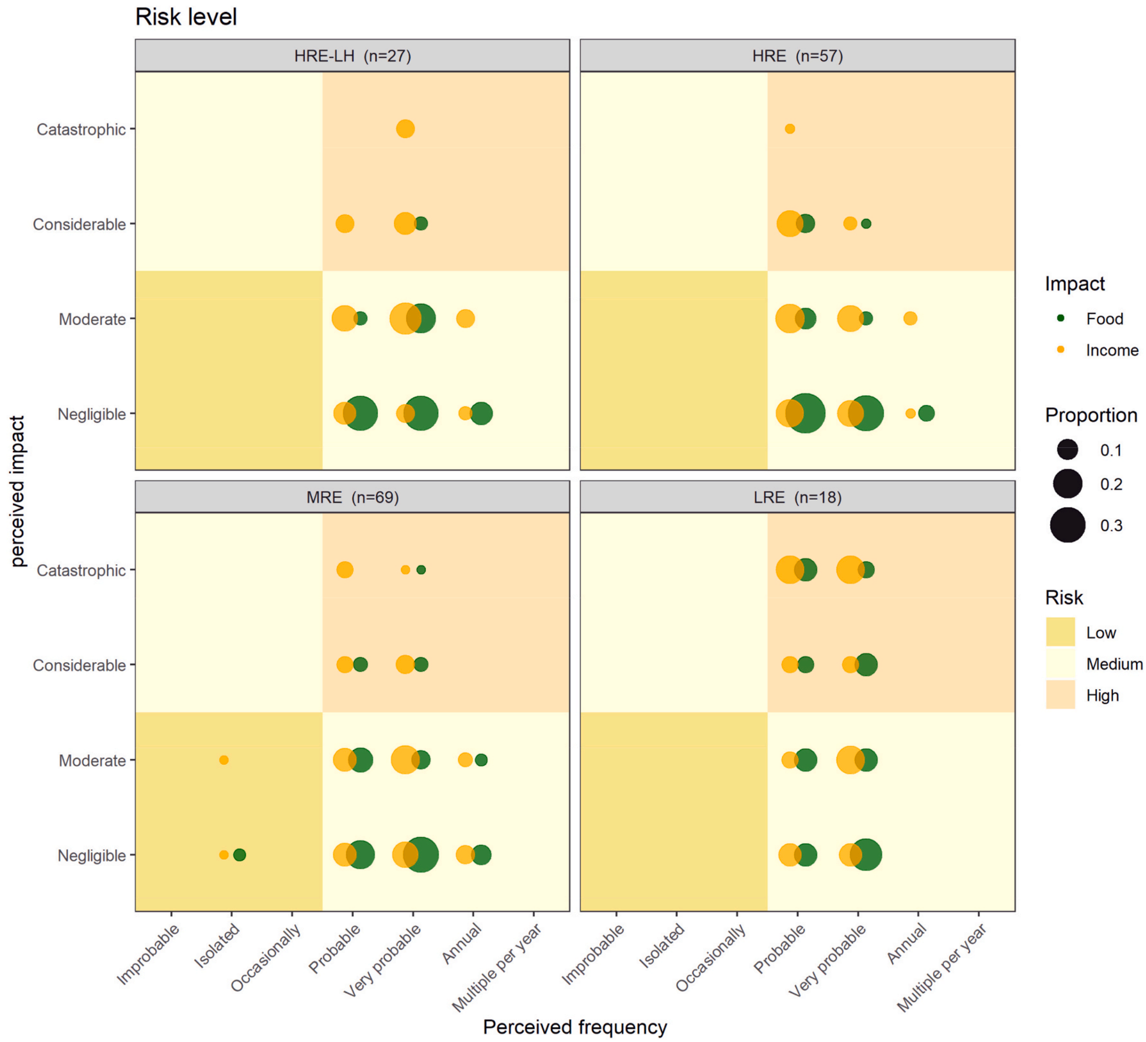

Fig. 6. Perceived impact on food availability and income and frequency of the hazards per farm type: High Resource Endowed farms with a Large Herd or HRE-LH ($n = 27$), High Resource Endowed Farms or HRE ($n = 57$), Medium Resource Endowed farms or MRE ($n = 69$) and Low Resource Endowed farms or LRE ($n = 18$). The size of the dots indicates the proportion of farmers of that farm type who mentioned this combination of frequency and impact. The background colour of the quadrants represents the risk level. Impact scores are: none or negligible (losses $< 5\%$), moderate (losses 5–15%), considerable (losses 15–50%), catastrophic (losses $> 50\%$). Frequency is indicated as follows: improbable (every 40 years), isolated (every 20 years), occasionally (every 10 years), probable (every 5 years), very probable (more or less every 3 years), annually, and multiple times a year.

Table 2
Examples of reactive and preventive risk management actions (reactive or preventive), categorized according to the farm component where change occurs, and the percentage of the cases in which that action was applied of the total number of risk cases described ($n = 171$). The set of actions is linked to the corresponding risk management strategies following (Schaper et al., 2010).

Farm component	Reactive risk management actions (ex-post)		Preventive risk management actions (ex-ante)		Risk management strategies applied
	%	Examples	%	Examples	
Nothing	23	–	30	–	Acceptance
Field	19	Change variety; re-sow; harvest early	9	Early maturing varieties; spread sowing dates; germination test	Reduction
Medical	18	Traditional or modern medical treatment	15	Traditional or modern preventive treatment	Reduction
Social	16	Remittances; borrow oxen; seeds or food in the village; get credit	16	Sell in group; associate with cooperatives; keep family reunions	Transfer, Reduction
Animal	15	Sell animal; stall feeding; buy or loan ox	11	Buy animals; store more fodder	Reduction
Inputs	13	Increase dose of fertiliser; buy other product; change targeted crops	8	Increase production of organic fertiliser	Reduction
Consumption	11	Buy or sell more cereals; consume lower diversity of food	3	Calculate how much cereal the family needs and store this amount; sell less	Reduction
Crops	10	Reduce cropped area; change crops	15	Cultivate fodder; reduce cropped area	Reduction
Labour	10	Work harder; hire labour; off-farm labour	5	Off-farm labour	Reduction, Avoidance
Other	0	–	8	Build a granary; buy material	Reduction

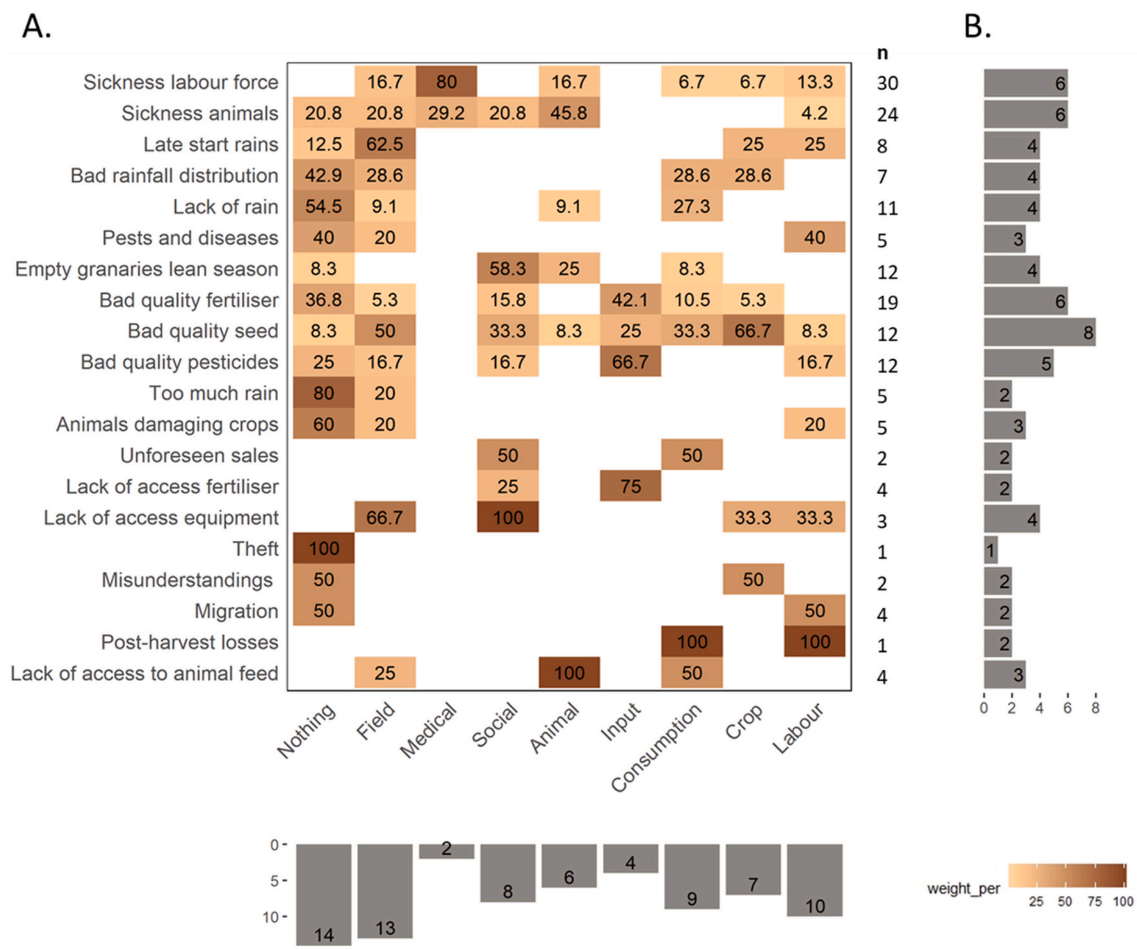

Fig. 7. (A) Heatmap of the actions per farm component applied as reactive management to the different hazards, with the intensity of the colour representing the abundance of an action to deal with a hazard. The number in the boxes represents the percentage of cases that a specific action was applied out of the number of hazard cases described by farmers (n). Several actions could be applied simultaneously by the same farmer, so that the sum of the rows is 100% or more. The hazards are ordered according to farmers' ranking, and the actions are ordered according to the number of times they were applied (total count). (B) The bar chart on the right represents the number of actions that have been applied for every hazard. (C) The bar chart on the bottom shows the number of hazards for which that action has been applied.

33% of cases for LRE farms, compared with 5–10% for the other farm types.

3.4. Risk management strategies

Farmers applied a broad range of both reactive and preventive risk management actions (Table 2, Fig. 7). Nevertheless, many farmers accepted the risk without applying a reactive response (23% of the cases), and this for a diversity of hazards. In addition, in 30% of cases farmers mentioned not to apply preventive actions.

With respect to the agronomic domain, farmers adapted their field management in 19% of the cases by re-sowing, possibly with another variety, or changing the harvesting date. Specific changes in input management (13% of reactive cases) included increasing the dose of fertiliser, buying a new product when the quality seemed inadequate, or applying the fertiliser to other crops. Whereas field and input management were less common as preventive strategy (9% and 8% of cases respectively), changing the choice of crops (e.g. growing more fodder crops) at farm level was used more often as a preventive (15%) compared to a reactive action (10%).

Changing animal management is mentioned as a reactive (15%) and preventive (11%) action to increase draught power (buying or borrowing oxen), or to obtain cash (selling animal). Farmers tried to adapt the storage of feed and feeding regimes to keep the animals healthy during the dry season.

Other management occurred in the socio-economic domain. Adapting the amount of sold cereals was mostly a reactive action (11%). Some farmers consumed less diverse food than they preferred when hazards affected their food availability. In 16% of the cases, farmers relied on their social network to ask for remittances, loans or credit in the village. Farmers did not rely on official credit schemes for cash. As a preventive action, farmers saw benefits in joining co-operatives, or less formalized group sales (16%). To a lesser extent, farmers adapted the labour division of household members (10% reactive, 5% preventive) or hired people. Sending household members to conduct off-farm labour was both an ex-post and ex-ante action. Medical treatment was applied for mitigating health risks of people and animals (18% reactive, 15% preventive), by applying both traditional and modern care.

Most actions were part of a risk reduction strategy (Table 2). Farmers that did nothing accepted the risk. Risk transfer occurred through social interactions. Agricultural risk avoidance could only be seen in seeking off-farm labour or migration when this would replace agricultural production. However, in our results, off-farm work was an addition to farming rather than a replacement.

For most hazards, no action appeared as the standard solution used by all farmers. Fig. 7 and Fig. S4 illustrate that a diversity of actions was applied per hazard, and that a single action could be used for different

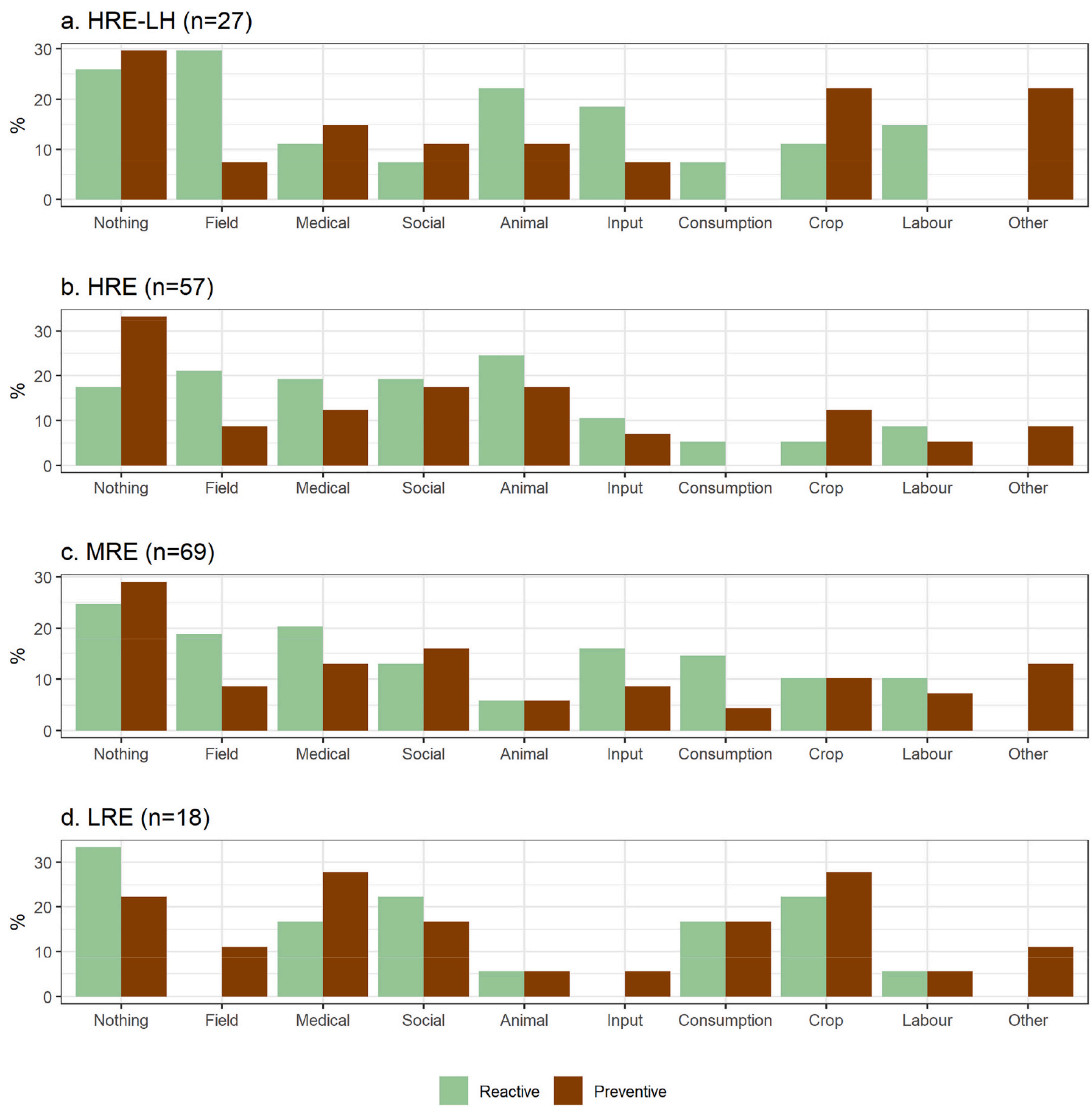

Fig. 8. Bar charts for the four farm types representing the percentage of the times a reactive or preventive management action was applied out of the total number of hazards described. The four farm types are High Resource Endowed farms with a Large Herd (HRE-LH), High Resource Endowed farms (HRE), Medium Resource Endowed farms (MRE) and Low Resource Endowed farms (LRE).

hazards. For example, changing field management (for 13 different hazards), changing labour assignments (ten hazards), changing consumption patterns (nine hazards), and calling on social interactions (eight hazards) were applied as reactions to a large range of hazards (Fig. 7). Medical action was very much targeted to the hazards of human and animal health, yet it was not the exclusive action. For example, to obtain cash for treatment some farmers mentioned selling cereals (reducing consumption of own cereal produce; farm component "consumption") or animals (component "animal"). Weak animals prompted some farmers to switch from animal labour for land preparation to mechanical labour by renting a tractor (component "field") or to using draught power by cows instead of oxen (component "animal"). The ex-post actions were more diversified for the higher ranked hazards compared to the hazards perceived as less important.

With respect to preventive management, farmers relied on social and institutional interactions for several hazards (ten) (Fig. S4), such as trying to influence CMDT for guaranteeing quality and uniformity of inputs. Likewise, adapting crop choice was commonly applied for nine hazards. Namely for the climate-related hazards, farmers included early maturing cereal varieties on their farm, or increased the area of millet, which is more drought-resistant.

All farm types applied a similar range of management actions (Fig. 8). However, the higher resource endowed farms (HRE, HRE-LH), who also have larger herds, referred to animal related actions more often. LRE did not mention changes in input use and field management but adapted cereal consumption rates more frequently as a response to hazards affecting the farm. All farm types called upon social interaction, yet the HRE-LH to a lesser extent.

4. Discussion

4.1. An agricultural system with abundant risks

Climate-related hazards were important for farmers, in line with literature that describes the frequent risks of weather variability, which are likely to increase with climate change (e.g. Akumaga and Tarhule, 2018; Schmitt Olabisi et al., 2018; Tiepolo et al., 2018). Yet farmers had concerns for a much broader range of hazards (Fig. 2), which are often not given enough attention (Komarek et al., 2020). Indeed, we identified health hazards as the most worrying for farmers. Also in other regions in Mali, farmers prioritized health above the need to improve land use practices (Ollenburger, 2019). Paradoxically, the health hazard from using pesticides was perceived to be least important. Nevertheless, in Mali pesticides are applied mainly on cotton and given the rare use of protective gear, this can be hazardous to health (Jepson et al., 2014). The large perceived importance of hazards related to the health of livestock affirmed livestock's importance for traction, manure and as a capital source (Traoré et al., 2017; Van Dijk et al., 2004). Decreasing forage and water resources during the last 30 years (Umutoni and Ayantunde, 2018) contributed to the difficulties of keeping animals healthy during the dry season. Finally, farmers doubted the quality of fertiliser acquired from the CMDT, which has been criticised openly in the past for providing low-quality inputs to contracted farmers (RFI, 2015; Theriault et al., 2018). This emphasises the need for institutions to guarantee input quality and (re-)build trust with the farmer community (Theriault et al., 2018).

The highest-ranked hazards occurred at the start of the growing season, which is a critical period for farmers' decision making (Traore et al., 2014). When the rainy season starts, farmers prepare their fields in a narrow time window (Soumaré, 2008), so if this start is disrupted, because of labour shortages or untimely access to inputs, the yield of maize, sorghum and cotton is often reduced (Traore et al., 2014). A further difficulty occurs when rains start late, forcing farmers to adapt their planning or to include short-cycle varieties, which usually have a lower yield potential (Traore et al., 2017; Traore et al., 2014). Also other periods of the year were risk-prone due to weather hazards and crop pests and diseases. Indeed, intra-seasonal climate risks are well described for this agro-ecological zone (Boansi et al., 2019) with dry spells negatively affecting crop growth especially during July and August. Hazards happening after the cessation of rain mostly affected the availability of food in the granaries (unforeseen sales, post-harvest losses, theft).

Surprisingly, market risks were of relatively little concern. This contrasts with risk assessments carried out elsewhere in Africa, where the volatility of crop prices was an important source of risk (Gebreegziabher and Tadesse, 2014; Kisaka-Lwayo and Obi, 2012). Farmers in northern Ghana for example ranked variability of input (fertiliser) and product (crop) prices as the second and third most important risks (Asravor, 2018). In Mali however, both the access to subsidised fertiliser on credit and the guaranteed off-take of the main cash crop cotton is coordinated by the CMDT (Laris et al., 2015; Theriault and Tschirley, 2014). Although fluctuating world prices of cotton affected farmers in the past (Falconnier et al., 2015; Van Dijk et al., 2004), normally cotton and fertiliser prices are fixed well before the start of the season so that farmers can incorporate this knowledge in their seasonal planning. Hence, the presence of CDMT possibly buffers some of the market risks to which farmers would otherwise be exposed. Another possible explanation for low perceived market risks, is that most farms are food self-sufficient (Falconnier et al., 2018) and therefore relatively independent of the market for their basic food needs.

4.2. Uniformity, as well as diversity, in risk perception

Our analysis showed that perception differed among and within households, but that differences were small and often occurred for specific hazards that were not ranked in the top five (Figs. 3, 4, 5). In other words, the most important risks were of concern for everyone.

Much literature suggests that women in sub-Saharan Africa are more vulnerable to climate related hazards than men (Perez et al., 2015), linked, among others, to a gender-based division of labour in agriculture, and unequal access to land and equipment (Droy et al., 2012; Guirkinger and Platteau, 2015; Paresys et al., 2018). However, no gender-defined pattern was observed in our data on risk perception, except for market risks (Fig. 4). Women mentioned they often sell vegetables or household products on a small scale in order to buy condiments or small goods for the family. Hence, they have more regular market contact, compared with men who are involved in seasonal transactions of cotton and cereal. In the Sahelian region of Senegal differences in preoccupations between women and men mostly related to constraints rather than risks (Tschakert, 2007). Similar as in our study, Senegalese farmers' mainly worried about health, which was ranked equally by men and women.

We found the clearest difference in risk perception between generations, with the household heads and the heads of labour most concerned (Fig. 5). As in similar farming systems in West Africa, decision power is related to gender and generation (Michalscheck, 2019). As risk concern tends to decline with age (Asravor, 2018), decision power probably is a better explanatory factor for risk perception than age itself, or gender. Rural youth often have other aspirations than a life in farming (Van Dijk et al., 2004) and seek education and employment through (seasonal) migration (Kanté, 2001). Possibly the tempered interest in farming, next to limited decision power in the household, lowered the risk perception of young people.

The positive relationship between resource endowment and land productivity in southern Mali (Falconnier et al., 2015) did not translate into large differences in risk perception between farm types (Fig. 3). However, the two farm types (LRE and HRE) with the lowest income per capita (Falconnier et al., 2018) had a slightly, yet significantly higher concern for risks. HRE have more resources at farm level than MRE, but they also have more mouths to feed (Falconnier et al., 2015). Likewise, with more people in the household it is not surprising that both the HRE-LH and HRE had a greater concern for hazards related to social interactions than the two other farm types.

LRE farmers were not only more concerned with hazards, but also described the impact, especially on food availability as more severe compared to other types of farmers (Fig. 6). The relatively high food availability risk implies that LRE farms lack food surplus or income to compensate for some of the food production losses. In contrast, when a hazard affected the better-off farms, the impacts more often remained negligible or moderate. Indeed, Struif Bontkes and van Keulen (2003) found that farmers who cultivated larger land areas were more prepared and capable to take risks than farmers owning less land. Even then, also the better endowed farmers were very concerned for risks. Although farmers are generally food self-sufficient, only 25% of farms, mostly the HRE-LH, are both above the poverty line and food self-sufficient (Falconnier et al., 2018). Hence, the majority of farmers are vulnerable to losses, which may induce a poverty trap when resources are used to recover from shocks and can no longer be used to invest (Hansen et al., 2019). Furthermore, several hazards occurring in the same year (Fig. S1) can aggravate losses, which may influence the perception on impact of each individual hazard.

Our results (Fig. 6) did not confirm the expected prevalence of hazards occurring with low frequency-high impact on the one hand and high frequency-low impact on the other hand (World Bank, 2016). Whereas the risks in Fig. 6 reflect farmers' interpretation of the hazards they find most relevant in their farming system, additional hazards with other frequency-impact combinations may exist. Farmers' concern for high probability hazards could possibly be explained by farmers' vulnerability, since the majority lives below the poverty line. As such, any small shock could already be perceived substantial, because even relatively moderate losses may surpass farmers' reserves. When hazards happen very often, the degree of uncertainty disappears and they could be defined as constraints instead. Nevertheless, we interpret the listed hazards not as constraints because they all relate to an event and not to a fixed state and in interactions with farmers the uncertainty of hazards was emphasized. Moreover, a minority of farmers said that the hazards happened every year.

4.3. Diversity of risk management strategies

Farmers dealt with a diversity of hazards through applying diverse strategies; there was no single solution for every specific problem

(Table 2, Fig. 7 and Fig. S3). Diversification is common for communities in semi-arid areas to deal with uncertainty and variability (Mertz et al., 2008; Mubaya and Mafongoya, 2016), which can effectively mitigate the everyday risks farmers face (Brouwer et al., 2007). The available resources used to deal with risks differed slightly between farm types (Fig. 8). For example, higher resource endowed farms (HRE-LH and HRE), with larger herds (Table S1), relied more often on livestock, whereas LRE farms called more on social interactions. To structure the diversity of risk management actions, we discuss them according to the following four strategies: risk acceptance, reduction, transfer and avoidance in the following paragraphs (Schaper et al., 2010).

Risk acceptance was common. Many farmers in our study did not deal with hazards, especially not through preventive actions and when applied, these were mostly short term. First, this could be explained by a lack of knowledge on feasible risk management strategies, or investment needs beyond the farmer's capacity (Schaper et al., 2010). Secondly, farmers possibly do not apply actions for specific hazards, but have risk spreading inherently built into the farm structure by diversifying crops, varieties and livestock on their farms (Mertz et al., 2008). Some farmers said that they did not apply any action, except for praying or making traditional sacrifices. When related to rainfall events, the latter is often a communal activity and demands some investment and solidarity from farmers (Jonckers, 1976). We categorized these actions as “risk acceptance”, since farmers themselves classified them as “doing nothing”. Overall, farmers focused more on ex-post risk management, and not as much on specific risk management planning that deals with uncertainty.

Actions categorized under risk-reduction were applied with the intent to decrease the farms' sensitivity to the impact (e.g. selling animals to generate income), or to decrease the probability of the hazard (e.g. preventive health treatments). The reactive actions only intended to reduce the impact, and indicated the flexibility of farmers' management when a hazard strikes. For example, farmers commonly change the planned variety of a crop when rains start late. Farmers applied reactive and preventive risk reduction through diversifying agronomic technologies or by using productive assets to overcome losses.

Diversification was a common risk reduction strategy at field and farm level. For example, sowing dates were targeted strategically or spread. The former could increase production (Traore et al., 2014), while the latter decreases chances of crop failure (Milgroom and Giller, 2013). Next, farmers mentioned to increase fodder crops in their rotation. Improving feeding regimes of cattle through stall feeding in the dry season can improve the health of animals and increase the potential of milk production (de Ridder et al., 2015). Furthermore, farmers sent family members to do off-farm work to have another source of income. This can provide a safety net and help in maintaining food security (Douxchamps et al., 2016).

Using productive assets as a risk reduction strategy can lead farmers into a poverty trap (Hansen et al., 2019). Farmers mentioned that they would work harder or consume less diverse foodstuffs. Wichern (2019) describes this same strategy by poorer farmers in Uganda who have limited options for coping with climate variability. Especially the larger farms (HRE-LH and HRE) sold livestock to cope with losses. This is a common coping practice in time of food shortage for farms with a cattle herd (Traoré et al., 2017; Wichern, 2019), whereas farmers owning few livestock typically turn to borrowing cash (Traoré et al., 2017).

With respect to risk transfer, social interactions were very important for farmers who relied on family and community members in time of need, or when preparing for risks in the future. As farmers did not mention formal insurance schemes, risk transfer only happened informally by farmers borrowing from each other or relying on remittances. Although some farmers sold cereals in group, transferring the risk to buyers through long term contracts with guaranteed prices was not mentioned for products other than cotton. This means there is scope to strengthen the role of cooperatives to increase farmers' negotiating power, as well as to investigate opportunities for insurance schemes. However, such formal structures may damage the existing social cohesion (Sidibé et al., 2018). Perez et al. (2015) suggest that interventions in the social domain should be gender sensitive, since men and women rely on different kinds of networks. Men tend to join formal, regional networks more easily, while women usually connect to informal groups within the community.

Besides risk acceptance, reduction and transfer, the fourth strategy is risk avoidance (Schaper et al., 2010). However, our results do not include such actions, since we asked for hazards that they worried about. This implies that they were still exposed to the hazard. Nonetheless farmers, especially LRE, reported on hazards with high impact and probability (Fig. 6), which suggests that farmers have no other choice than to keep farming and do not have the means for risk avoidance. In addition, although farmers are poor and potentially caught in a poverty trap, they seem to be able to overcome regular and substantial losses, suggesting robustness of the farming system as a consequence of the diversity of risk management practices. Yet, this robustness may suggest the households are simply “hanging in” (Dorward, 2009), and the R4 Rural Resilience Initiative (WFP and Oxfam, 2019) suggested that livelihoods could be improved if farmers would have the means to take prudent risks. This could also enhance the adaptability and transformability of the system, which together with robustness, are key components of resilience (Meuwissen et al., 2019).

4.4. Methodological considerations for future research

We focused on farmers' interpretations of the hazard, as well as their perceptions on and experiences with those hazardous events. The consequences of this approach need to be considered when interpreting the results. Firstly, the hazards are not independent of each other (Brooks, 2003). For example, when farmers are confronted with empty granaries, this is a result of one or more other hazards such as production shocks (pests, bad rainfall) or post-harvest losses. Simultaneous incidence of hazards makes it hard to measure the exact contribution of each event to the impact (World Bank, 2016). Secondly, some hazards could also be interpreted as representing a longer lasting trend, such as the incidence of soil erosion, or the lack of animal forage (Umutoni and Ayantunde, 2018). Finally, interpretation of risk and risk management may differ between farmers and researchers. We tried to minimize this by setting clear definitions, conducting several rounds of discussions, and involving local, trained enumerators in the survey work.

Our analysis gives a snapshot in time. Risk perception can be dynamic in a changing environment (van Winsen et al., 2011) or be stable over time (Wustro and Conradie, 2019). In our research there are arguments for both possibilities. For example, in 2018 the region was struck by foot and mouth disease, which was relatively unknown to farmers and could have influenced the focus on animal health hazards. All data is based on farmers' perception and recollection, so the recall period may have influenced their answers (Nikoloski et al., 2018). The period in which the survey was conducted spanned the course of the rainy season (May–October 2018). This may have directed farmers' attention toward common hazards for that specific time. Furthermore, younger respondents might be less influenced by hazards that are infrequent and did not occur yet during these farmers' lives. Many farmers indeed described recent events, but some farmers recalled events that happened almost 20 years ago (Fig. S1).

The approach enabled us to assess the diversity of risks encountered by farmers, filling a gap in risk research which often focuses on a single hazard (Komarek et al., 2020). This research describes applied and intended strategies but does not intend to assess their effectiveness. Quantifying the effects of hazards on farm production, as well as the mitigating effects of farm management and policy strategies could shape a following step of research.

5. Conclusion

Farmers deal with a broad range of risks, with production and human risks more important than financial, legal or market risks. Human and animal health, and climate-related hazards were of great concern for everyone, regardless of the farmers' resource endowment. Risk perception differed among farms and household members with the largest difference between generations and degrees of decision power. Farmers reacted to these risks with a variety of practices, although many farmers had no solution, especially for preventing risks. Both the hazard and the risk management strategies are influenced by off- and on-farm factors. Whereas research on poverty alleviation has often focused on on-farm components (Brooks, 2003), our findings suggest a need for research and policy to develop both off- and on-farm innovative options to enable farmers to adequately react to and prepare for risks. For example, farmers who want to diversify their varieties need access to good quality seeds; farmers who want to form a co-operative need information and formal means to do so; access to a local weather forecast could help farmers in preparing their field management. The hazards (partly) born outside of farmers' influence emphasize the need for improvements in health care, opportunities for off-farm work and farmers' capacity building. Providing access to micro-credits, could allow households to invest in their farms and take prudent risks that also carry the opportunity to improve their livelihood (as is promoted by the R4 Rural Resilience Initiative (WFP and Oxfam, 2019).

With respect to on-farm management options, our risk analysis identified some key traits of suitable options for the risky environment of southern Mali. Options should (i) be complementary to each other in their suitability for different weather situations, (ii) not increase labour requirements especially in the beginning of the season, (iii) focus on quality fodder production to improve feeding regimes of cattle, or (iv) strengthen cooperation or increase negotiating power of farmers.

The differences in risk perception and management between farm types were subtle, but taking into account the available resources of farm types they suggest how to tailor options. The impact of hazards on food availability was relatively strong for the poorer households. Therefore, food security should be a main priority for LRE farms. These farms also rely on their social network and could be supported in joining community associations. Options for better animal management could be targeted to the higher resource endowed farmers. The complexity of farmers' risk realities indicates that development interventions should address both socio-economic wellbeing and agronomic options to improve the livelihood and resilience of farmers in southern Mali.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2020.102905.

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