American Journal of Water Resources, 2025, Vol. 13, No. 6, 190-197
Available online at http://pubs.sciepub.com/ajwr/13/6/2
Published by Science and Education Publishing
DOI:10.12691/ajwr-13-6-2

Impacts of Flooding on Actors in the Maize Value Chain in Southern Benin

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Received October 06, 2025; Revised November 08, 2025; Accepted November 16, 2025

Abstract Climate change, manifesting as frequent floods, constitutes a systemic threat to food security in West Africa, particularly in Benin where maize production is essential. The problem lies in the heterogeneous vulnerability of actors in the maize agricultural value chain, a differentiation often overlooked below national scales. This study aims to analyze the differentiation of flood impacts on the seven categories of maize agricultural value chain actors. The hypothesis posits that the effect of an actor's position on the experienced impacts is significantly modulated by age, gender, and education level. A mixed sampling approach (probabilistic and snowball) was used to survey 1,128 value chain actors in Southern Benin. Moderate logistic regression models were applied to evaluate the significant interaction terms. The most common impacts are poor sales, financial loss, corn grain rot, poor digestion of consumed corn, and the decrease in income respectively for input and seed suppliers, producers, animal feed manufacturers and suppliers, processors, traders and consumers, and carriers. Vulnerability is a highly heterogeneous product of social and structural interactions. Gender is the most divisive moderator, while education confers technical resilience but paradoxically increases vulnerability to systemic failures. Age offers experience-based resilience while increasing logistical constraints for carriers and traders. The results highlight the imperative of adopting an intersectional risk management strategy, where interventions must be specifically tailored to socio-demographic profiles to avoid exacerbating inequalities within the maize agricultural value chain.

Keywords: *agricultural value chain, vulnerability, floods, moderation, cereals*

Cite This Article: Kolawolé Saïd HOUNKPONOU, Rodéric Roland Singbénou SAGBO, Mondukpè Viviane GBENOU, Sedjro Gilles Armel NAGO, and Jacob Afouda YABI, "Impacts of Flooding on Actors in the Maize Value Chain in Southern Benin." *American Journal of Water Resources*, vol. 13, no. 6 (2025): 190-197. doi: 10.12691/ajwr-13-6-2.

1. Introduction

Climate change has become an urgent global concern, posing a major challenge to the agricultural sector [1,2]. The agricultural sector, being essential for sustaining food, income, and employment, is subject to considerable vulnerabilities [3]. The effects of climate change, which are both direct and indirect [4], manifest through climatic extremes such as drought and frequent floods, threatening food security and biodiversity [4]. These climate-induced phenomena severely affect cereal yields [5], with staple crops being particularly vulnerable, thereby exacerbating the risk of food insecurity [6,7]. The main impacts of flooding are related to soil fertilization, destruction of agricultural products [8], economic inflation [9], and reduced agricultural income [10,11], poor quality and lower production yields [11], loss of human life, material damage, loss of income for stakeholders, cases of diarrheal diseases and malaria, soil erosion, and pollution of water and nature [12].

The impacts of climate change are particularly direct and critical in Africa, especially for the livelihoods of smallholder farmers [13]. Maize, as a staple food, plays a crucial role in the food security of African countries [14], including Benin, which is currently facing climate vulnerability [15]. Maize production is highly sensitive to climate shocks, with the impact of temperature and precipitation on yield being non-linear and generally negative [2,16,17].

Several challenges arise, including research into improving high-resolution climate forecasts, optimizing regional water governance, improving cross-sector data sharing, and promoting ecological restoration [18] to strengthen resilience in agricultural value chains. Despite ongoing efforts, the lack of funding and institutional support, insufficient stakeholder involvement and consideration of ecological and sociocultural factors, and limited access to meteorological information [19,20] pose real challenges.

Indeed, the potential impacts of climate change on agricultural value chains are rarely analyzed jointly below national scales, which tends to mask substantial variability in how communities are affected [13]. Climate change vulnerability assessment is, however, an essential technique for identifying critical areas and planning adaptation [21]. Crucially, vulnerability to climate shocks differs not only between small agricultural communities but also among farmers within the same production system [22]. This variation is strongly and significantly explained by socio-economic and demographic factors [22].

It therefore becomes essential to refine the analysis of this vulnerability by integrating the value chain as a framework for study beyond just producers. While an actor's position determines their exposure to specific impacts, the way they experience these impacts can be modulated by their socio-demographic profile. Such an approach is necessary to move beyond simple risk identification and understand the mechanisms of vulnerability transmission and differentiation across the chain.

The present study aims to analyze the differentiation of flood impacts on actors throughout the maize agricultural value chain. The hypothesis guiding this research is that the effect of an actor's position in the maize value chain on the experienced impacts is significantly moderated by the actor's age, gender, and education level.

2. Material and Methods

2.1. Study area

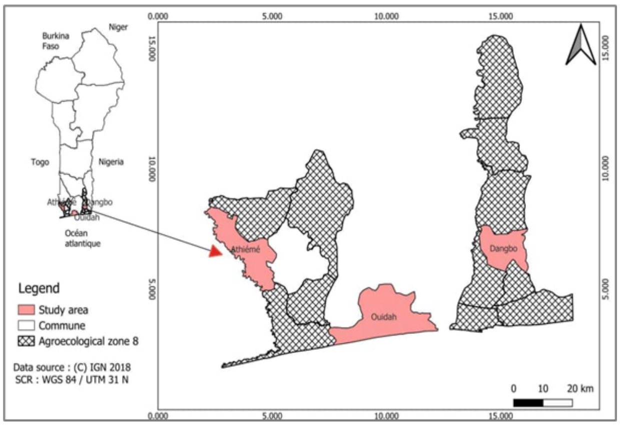

Figure 1. Study area

This research was conducted in three specific municipalities (Athiémé, Dangbo, and Ouidah) located in Southern Benin (Figure 1). These sites were chosen due to their dual significance: they are key maize-producing areas within agro-ecological zone 8 and simultaneously exhibit high vulnerability to recurrent flooding in southern Benin. The climate of the region is characterized as a bimodal Sudanian regime, resulting in four distinct seasons annually: a long rainy season (Mid-April to early July), a short rainy season (September to November), a long dry season (December to early April), and a short dry season (from late July to early September) [23,24]. The average annual rainfall typically falls between 900 mm to 1300 mm. The thermal conditions are relatively stable, with an average annual temperature of 27°C and high relative humidity, generally around 80%. However, extreme temperatures can reach up to 38°C [25]. The prevailing soil types are ferralitic, supplemented by localized formations of lateritic, clay, and hydromorphic soils [25]. Agricultural activities in this area focus on growing a diverse array of staple crops during the long rainy season, including maize, rice, cowpea, groundnuts, cassava, and soybean. Notably, maize cultivation also dominates the short rainy season [24].

2.2. Methods

2.2.1. Sampling

The research employed a sequential mixed-method sampling strategy, which combined non-probabilistic and probabilistic techniques to ensure comprehensive coverage of the study population. An initial exploration phase was executed to comprehensively identify and map all relevant actors across the maize Agricultural Value Chain (AVC) within the designated study municipalities. This preparatory step was crucial to define the population parameters and ensure the subsequent sampling frame included all participant types based on the established functional links within a typical AVC. Official lists of these identified actors were subsequently compiled utilizing information sourced from relevant local authorities and people.

The sample size was determined mathematically to guarantee statistical representativeness. This calculation (Eq.1) was based on the formula proposed by [26], a methodology frequently employed in similar regional studies [27,28]:

$$n = (U^2_{1-\alpha/2} x\, p(1-p)) / d^2 \quad (1)$$

Where $U_{1-\alpha/2}$ (α = 0.05) = 1.96, d: the margin error=5 %, the estimated proportion p = 0.50.

Due to the lack of updated or available lists of all value chain actors, a snowball sampling method was also used to identify additional survey participants [29,30]. This mixed-method sampling approach helped ensure a comprehensive representation of the various roles within the maize value chain.

In total, 1,128 actors (53% are men and 47% are women) over the age of 18 were surveyed, distributed as follows: Input and seed suppliers (16), producers (396), Animal feed manufacturer and suppliers (5), Processors (95), Traders (81), carriers (47), Consumers (488).

2.2.2. Data Collection

Data were collected from various local and communal actors involved at different levels of the agricultural value chain (AVC) through semi-structured interviews. Each survey was carried out after obtaining verbal consent from the participants [31]. The focus of the data collection was on climate related impacts and sociodemographic characteristics (Table 1).

2.2.3. Data Analysis

We ran moderate logistic regression models [32] to study how sociodemographic variables moderate the relationship between an actor's position and the impacts to which they are vulnerable, after descriptive statistics, using R Studio [33]. The statistical model used in the R script is the Generalized Linear Model (GLM) of the binomial family (Table 2). These models were found to be globally significant (p.value< 0.05). The analysis used the ggplot2, tidyverse and broom packages.

Table 1. Variables coding

Data	Coding
Age	Continuous variable
Gender	Binary variable (0=Female, 1=Male)
Education level	Ordinal variable (0=None, 1=Primary, 2=Secondary, 3=Higher)
Position in the value chain	Binary variable (0=No, 1=Yes)
Impacts	Binary variable (0=No, 1=Yes)
Legend of impacts	
CGR	Corn grain rot
CL	Crop loss
DDSC	Difficulties in drying and storing corn
DS	Decrease in income
DY	Decrease in yield
FL	Financial loss
FM	Famine
HPC	High price of corn
IG	Immature grain
IR	Impassable road
IRD	Increased risk of drowning
PDCC	Poor digestion of consumed corn
PQCBF	Poor quality of corn-based food
PS	Poor sales
SA	Slowdown in activities
SC	Scarcity of corn
UP	Unemployment

Table 2. GLM parameter estimates and global model significance

Impact	Term	Coef.	Std_Error	Global model p-value
CGR	Producer: Gender1	2.46	0.82	3.30e-17
DDSC	Consumer: EL1	1.69	0.60	1.51e-27
DDSC	Consumer:EL2	2.93	0.71	1.51e-27
DDSC	Consumer:Gender1	3.53	0.55	1.20e-20
DDSC	Trader: EL1	-1.86	0.76	1.15e-15
DS	Producer: Gender1	-6.14	1.28	4.41e-16
DY	Consumer: Age	0.07	0.03	4.30e-22
DY	Producer: Age	-0.06	0.03	7.25e-41
FL	Consumer: Age	-0.05	0.02	1.43e-89
FL	Consumer:Gender1	-2.56	0.65	4.25e-98
FL	Producer: Gender1	2.44	0.66	4.72e-133
FL	Trader: Age	-0.10	0.03	1.81e-08
FM	Consumer:Gender1	-1.10	0.31	7.61e-26
FM	Producer: EL1	0.81	0.34	6.06e-17
FM	Producer: EL2	0.96	0.42	6.06e-17
FM	Producer: Gender1	0.87	0.41	5.87e-21
HPC	Consumer: Age	0.03	0.01	5.40e-129
HPC	Consumer: EL1	1.41	0.42	3.78e-127
HPC	Consumer:Gender1	3.69	0.48	1.79e-150
HPC	Processor: EL2	1.25	0.61	2.64e-03
HPC	Trader: Age	0.04	0.02	4.07e-05
HPC	Trader: EL1	-1.81	0.81	1.01e-05
IR	Carrier: Age	0.11	0.04	3.68e-24
IR	Carrier: EL1	1.76	0.80	2.09e-21
IR	Processor: EL2	1.89	0.81	1.68e-02
IRD	Consumer:Age	-0.13	0.05	1.12e-02
IRD	Trader: Age	0.09	0.04	1.19e-02
PDCC	Consumer:Gender1	-1.53	0.27	4.85e-22

PDCC	Processor: EL1	-1.52	0.69	1.55e-18
PDCC	Producer: Gender1	2.10	0.37	6.58e-27
PQCBF	Consumer: EL1	1.85	0.66	4.27e-32
PQCBF	Consumer:EL2	2.64	0.73	4.27e-32
PQCBF	Consumer: Gender1	3.34	0.56	5.03e-22
PQCBF	Producer: EL1	-3.25	1.28	3.56e-34
PQCBF	Producer: EL2	-3.01	1.29	3.56e-34

3. Results

3.1. Perception of Flooding Impacts on the Maize Value Chain in Southern Benin

The most common impact cited by 31% of input and seed suppliers was poor sales (PS). The least common impact was poor quality of corn-based food (PQCBF), mentioned by 3.4% of suppliers (Figure 2).

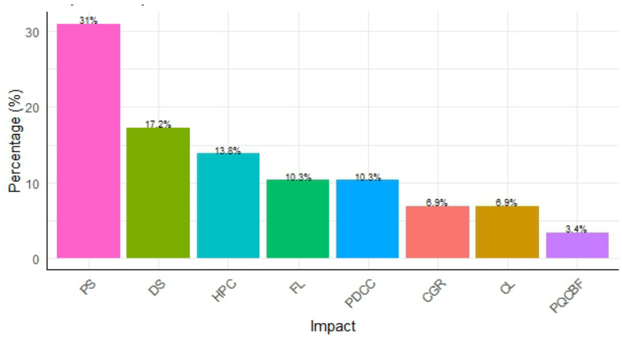

Figure 2. Impacts of floods on corn input and seed suppliers

The most common impact cited by producers (27. 8%) was financial loss (FL), while the least common impact was scarcity of maize (SC), mentioned by 0.7% of producers (Figure 3).

The most common impact cited by 28.6% of animal feed manufacturers and suppliers was corn grain rot (CGR). The least common impact was immature grain (IG), mentioned by 14.3% of animal feed manufacturers and suppliers (Figure 4).

The most common impact cited by 30.9% of processors was poor digestion of consumed corn (PDCC), while increased risk of drowning (IRD) was the least mentioned by 1.6% of processors (Figure 5)

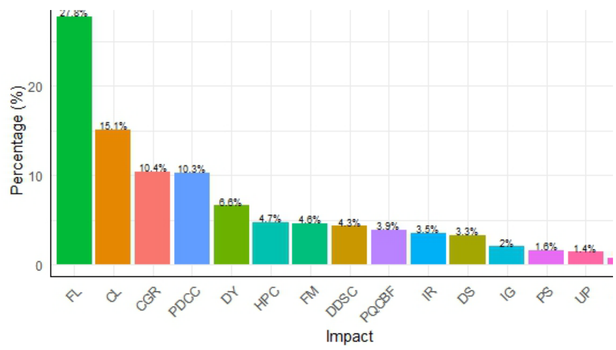

Figure 3. Impacts of floods on corn producers

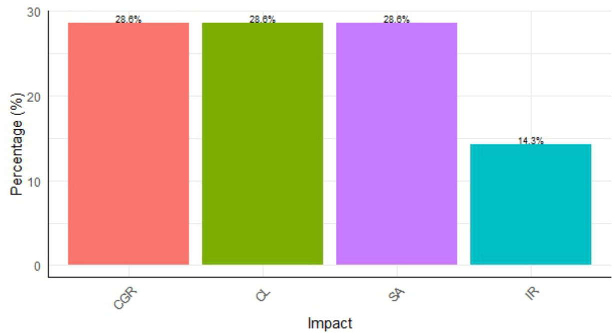

Figure 4. Impacts of floods on the corn-based animal feed manufacturers and suppliers

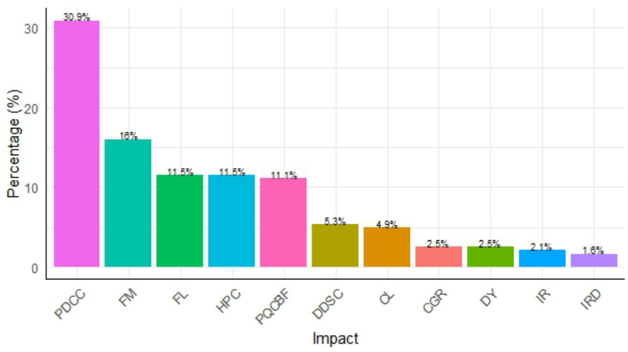

Figure 5. Impacts of floods on corn processors

The most common impact cited by 22.4% of traders was poor digestion of consumed corn (PDCC), while they were less affected by the decrease in income (DS), which was mentioned by 0.6% of traders (Figure 6).

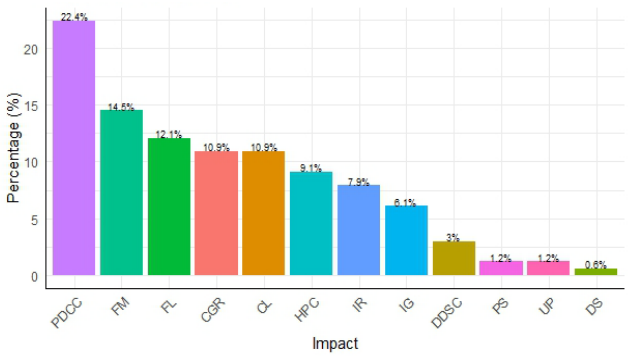

Figure 6. Impacts of floods on corn traders

The most common impact cited by 22.1% of corn carriers was the decrease in income (DS), while 2.3% cited the high price of maize (HPC), which was the least frequently mentioned impact (Figure 7).

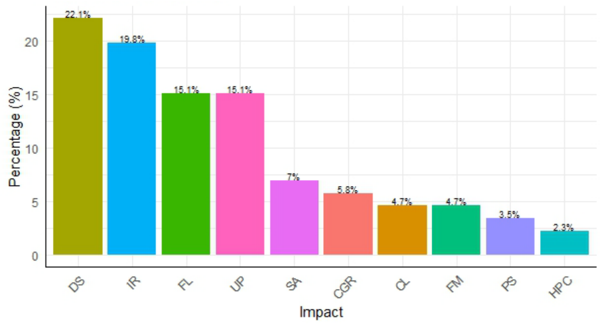

Figure 7. Impacts of floods on corn carriers

The most frequently cited impact was poor digestion of consumed corn (PDCC) (25.1%), and the least frequently cited was corn grain rot (CGR), mentioned by 0.4% of consumers (Figure 8).

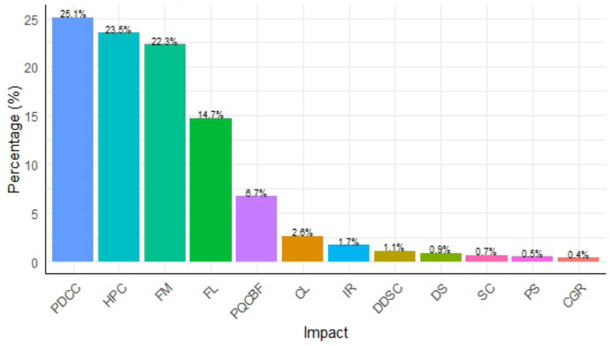

Figure 8. Impacts of floods on corn consumers

3.2. Effects of Socio-demographic Characteristics on the Relationship Between Maize Value Chain Actor Position and Flood Impacts

Socio-demographic characteristics (age, gender, and education level) significantly modulated the vulnerability of actors in the maize value chain (MVC) to specific flood impacts (Table 3).

According to the results, male consumers showed the highest positive interaction coefficients for HPC (3.69), DDSC (3.53), and PQCBF) (3.34). This suggested that men were the most exposed to structural failures in the value chain (price and logistics), possibly due to their roles in household provisioning or storage. Conversely, being male acted as an attenuating factor against more fundamental impacts related to subsistence and health: FL was strongly attenuated (−2.56), as were PDCC (−1.53) and FM (−1.10). This indicated that female consumers bore a disproportionate burden of the fundamental health and economic risks associated with food insecurity. The most prominent effect in the entire analysis was the extreme attenuation (−6.14) of DS for male producers. This finding implied that the producer status conferred a major economic resilience to men, likely through better access to income diversification mechanisms, productive resources, or sales networks, compared to female producers. In parallel, male producers were more vulnerable than their female counterparts to specific shocks, including CGR (2.46), FL (2.44), PDCC (2.10), and FM (0.87). The risk for male producers was thus concentrated on direct shocks affecting product quality and, consequently, related health issues.

Table 3. Effects of socio-demographic characteristics on the relationship between MVC actor position and flood impacts

Impact	Term	Coef.	Interactions p-value
CGR	Producer: Gender1	2.46	2.64e-3
DDSC	Consumer: EL1	1.69	5.18e-3
DDSC	Consumer:EL2	2.93	4.12e-5
DDSC	Consumer:Gender1	3.53	1.43e-10
DDSC	Trader: EL1	-1.86	1.44e-2
DS	Producer: Gender1	-6.14	1.76e-6
DY	Consumer: Age	0.07	1.75e-2
DY	Producer: Age	-0.06	2.01e-2
FL	Consumer: Age	-0.05	2.18e-2
FL	Consumer:Gender1	-2.56	7.65e-5
FL	Producer: Gender1	2.44	2.33e-4
FL	Trader: Age	-0.10	5.61e-4
FM	Consumer:Gender1	-1.10	3.52e-4
FM	Producer: EL1	0.81	1.79e-2
FM	Producer: EL2	0.96	2.25e-2
FM	Producer: Gender1	0.87	3.17e-2
HPC	Consumer: Age	0.03	4.35e-2
HPC	Consumer: EL1	1.41	7.95e-4
HPC	Consumer:Gender1	3.69	1.31e-14
HPC	Processor: EL2	1.25	4.01e-2
HPC	Trader: Age	0.04	4.55e-2
HPC	Trader: EL1	-1.81	2.54e-2
IR	Carrier: Age	0.11	8.76e-3
IR	Carrier: EL1	1.76	2.82e-2
IR	Processor: EL2	1.89	1.94e-2
IRD	Consumer:Age	-0.13	1.23e-2
IRD	Trader: Age	0.09	3.91e-2
PDCC	Consumer:Gender1	-1.53	1.11e-8
PDCC	Processor: EL1	-1.52	2.82e-2
PDCC	Producer: Gender1	2.10	1.76e-8
PQCBF	Consumer: EL1	1.85	5.15e-3
PQCBF	Consumer:EL2	2.64	2.77e-4
PQCBF	Consumer: Gender1	3.34	2.73e-9
PQCBF	Producer: EL1	-3.25	1.10e-2
PQCBF	Producer: EL2	-3.01	1.90e-2

Education Level (EL1 and EL2 levels) was associated with a very strong attenuation of PQCBF ([−3.25, −3.01]) for Producers. This suggested that higher education enabled better management and post-harvest practices to preserve maize quality. For Traders, EL1 strengthened resilience against DDSC and HPC ([−1.86, −1.81]). This implied that education improved access to information and networks, bolstering the capacity to navigate market and logistical risks. EL1 attenuated PDCC impacts (−1.52) for Processors. Conversely, education increased vulnerability in other groups, signaling greater reliance on and thus exposure to failing formal systems and infrastructure. EL1 and EL2 levels significantly increased vulnerability to DDSC ([1.69,2.93]) and PQCBF ([1.85,2.64]) while Education (EL1) also accentuated vulnerability to HPC (1.41) for Consumers. For Carriers and Processors, EL1/EL2 made these actors more affected by IR [1.76,1.89] while increasing the risk of FM ([0.81,0.96]) for Producers. This pattern suggested that more educated actors, who might have had higher expectations or greater dependence on formal value chains and critical infrastructure, suffered a stronger impact when these systems collapsed.

Age was a major attenuating factor against IRD (−0.13) and FL (−0.05) for Consumers, attenuated the impact of DY (−0.06) for Producers, and reduced the risk of FL (−0.10) for Traders. This suggested that experience and knowledge of risks conferred financial and physical resilience to older actors. Conversely, Age strongly increased vulnerability to IR (0.11) for Carriers, increased the risks of IRD (0.09) and HPC (0.04) for Traders, and slightly increased vulnerability to HPC (0.03) and DY (0.07) for Consumers. This suggested that the physical constraints associated with age could have made these actors more vulnerable to infrastructure shocks and market access difficulties.

4. Discussion

4.1. Influence of Sociodemographic Characteristics of Actors in the Maize Agricultural Value Chain on Flood Impacts

The objective of this study was to analyze the differentiation of flood impacts on actors in the maize agricultural value chain (AVC) and to determine the moderating effect of sociodemographic characteristics. The analysis of the 35 significant interaction terms confirms the research hypothesis: the effect of an actor's position on the value chain on the experienced impacts is significantly modulated by their age, gender, and education level (EL). These results demonstrate that floods vulnerability is highly heterogeneous and dependent on the actor’s profile [22]. The models are robust (Global model p-value less than 0.05), which validates the regression results.

Gender emerges as the most divisive moderator, creating a clear segmentation of risks that reflect sociocultural norms and inequalities in access to productive resources. Our results indicate major economic resilience for male producers, materialized by the extreme attenuation of decrease in income (DS). This protection suggests that men have better access to income diversification mechanisms and sales networks to absorb losses, a phenomenon often linked to their privileged access to productive resources [34]. In contrast, women (the reference group) bear the disproportionate burden of subsistence and health impacts among consumers (attenuation for men on financial loss (FL), poor quality of corn-based food (PDCC), famine (FM)). This aligns with findings that women are more vulnerable to the effects of climate impacts on food security due to their limited access to resources and social roles [35,36]. Conversely, the extreme vulnerability of male consumers to difficulties in drying and storing corn (DDSC) and High price of corn (HPC) shocks suggests that their provisioning role exposes them directly to value chain failures.

Education level (EL) reveals an ambivalent role, consistent with observations that education is a key factor in the ability to perceive and choose adaptation strategies [1,22]. On one hand, education confers essential technical resilience to upstream and midstream actors. The very strong attenuation of poor quality of corn-based food (PQCBF) for producers and difficulties in drying and storing corn (DDSC) and high price of corn (HPC) for traders indicates that a higher educational level enables better adoption of post-harvest management practices and better navigation of market risks. On the other hand, education is paradoxically associated with increased vulnerability to systemic failures (difficulties in drying and storing corn (DDSC) and poor quality of corn-based food (PQCBF) among educated consumers, impassable road (IR) among educated carriers and processors). This amplification of risk suggests that more educated actors, who depend more heavily on formal infrastructure (roads, supply systems) for their activities or consumption, suffer a stronger impact when these systems collapse. Furthermore, the exacerbation of flood-related vulnerability in maize production is linked to low education levels [37].

Age modulates vulnerability by reflecting the accumulation of experience [38]. The attenuation of increased risk of drowning (IRD) and financial loss (FL) among consumers is a sign of prudence and risk awareness, while the reduction of decrease in yield (DY) for producers and financial loss (FL) for traders indicates a capacity to better diversify or manage economic risks over time. However, age is also a source of logistical and physical vulnerability. The increased impact of impassable road (IR) on carriers and increased risk of drowning (IRD) on traders suggests that physical constraints associated with age can hinder actors' ability to maneuver and adapt to infrastructure shocks, a risk exacerbated by road degradation caused by floods [39].

4.2. Implications of Results and Future Research Perspectives

This study highlights the need to analyze the maize value chain beyond just producers, recognizing the importance of all other links, which face specific impacts that illustrate the systemic transmission of shocks along the chain. The results justify the adoption of an intersectional adaptation strategy that transcends the unitary approach. Interventions must specifically target female producers to strengthen their economic resilience against decrease in income (DS) [40], and risk education programs must acknowledge the increasing role of male consumers in managing logistical risks. Education, while a technical asset, is insufficient to create resilience against systemic failures. It is imperative to invest in the improvement of critical infrastructure (roads and storage) to reduce the disproportionate impact of shocks on actors, particularly carriers and processors. Specific support mechanisms must also be established for older carriers and traders to reduce their exposure to increased logistical and physical risks, for example, through specific climate information on impassable roads.

This study focuses on knowledge relating to the causal mechanisms of vulnerability. It would be relevant to conduct longitudinal studies to evaluate how changes in income diversification (away from agricultural dependence) and improved educational status for women modify household resilience following floods [40]. Furthermore, exploring the interaction between biophysical factors (land size, soil fertility) and socio-economic factors [22] would further refine vulnerability assessments. Finally, an in-depth analysis of actors' perceptions [38] regarding flood impacts across the different value chain links could enrich the understanding of adaptation strategies.

5. Conclusion

The findings converge to establish that vulnerability is a product of social and structural interactions. Gender segments economic risk, education confers technical resilience but exposes actors to systemic failures, and age offers experience-based resilience while increasing logistical constraints. These results underscore the necessity of risk management interventions that integrate an intersectional approach to effectively target the specific vulnerabilities of each actor profile. Interventions must not only target the position within the value chain but must be specifically tailored to socio-demographic profiles to avoid creating or exacerbating vulnerability inequalities. Finally, adaptation strategies such as crop improvement and agroecological practices are essential to ensuring agricultural resilience.

ACKNOWLEDGEMENTS

The authors thank the Direction Départementale de l'Agriculture, de l'Elevage et de la Pêche (DDAEP) of Atlantique, Mono and Ouémé (Benin) for authorizations to collect data, the local populations, the local field assistant and the students who provided technical support for the work.

Declaration of Authors

The authors declare no competing interests.

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