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Climate Change and Shea (*Vitellaria paradoxa*) Production in Northern Togo: Perceptions, Impacts, and Adaptation Strategies of Producers/Collectors

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The shea value chain in Northern Togo, a primary source of income for many rural households, faces intensifying climate hazards whose perceived impacts remain poorly documented. This study analyzes stakeholders' perceptions of climate change, its impacts, and their adaptation strategies. A mixed-methods approach combining 274 individual surveys and 8 focus group discussions was carried out between October and December 2025 in eight prefectures of the Savanes and Kara regions. Climate change is perceived by 99.27% of stakeholders, with strong spatial heterogeneity in risks: irregular rainfall in Dankpen (93.75%), bushfires in Doufelgou (94%), and strong winds in Cinkassé (65.96%). This heterogeneity reflects local geographic exposure, prefecture being statistically associated with perceived risk ($\chi^2 = 200.4$; $p < 0.001$; Cramér's V = 0.494), with no effect of sex, education, or experience. Marked phenological disturbances are reported, with flower abortion affecting 18.60% to 100% of respondents depending on the prefecture. An average perceived decline of 37.6% in nut production over the past 10 years was reported, varying by prefecture (Kruskal-Wallis, $p = 0.028$, $\varepsilon^2 = 0.066$), though this decline cannot be attributed solely to climate change, as other local factors may also contribute. Current adaptation strategies, whether structural or ritual, show low-to-moderate perceived effectiveness, pointing to a qualitative gap with the intensity of perceived risks that this study documents descriptively. These findings call for targeted adaptation policies that integrate local knowledge with scientific approaches.

Introduction

Climate change is one of the major challenges of the 21st century, affecting all ecosystems and human activities (IPCC, 2023). In West Africa, its effects are particularly marked: significant warming, a shift in the rainfall regime toward rarer but more intense rainfall, an increase in droughts and floods, and growing pressure on natural resources (Hulme *et al.,* 2001; Panthou *et al.,* 2018). These changes directly threaten rain-fed agriculture, which employs more than 70% of the working population and contributes 38% of Gross Domestic Product (GDP) in countries such as Togo (Gadedjisso-Tossou, Adjegan and Kablan, 2021). In this context, tree species in agroforestry parklands (including shea) play a crucial role in the resilience of rural systems. They provide non-timber forest products essential to food security and household income, while contributing to microclimate regulation and soil conservation (Hall *et al.,* 1996).

Shea (*Vitellaria paradoxa*) is an emblematic species belonging to the Sapotaceae family. This fruit tree is native to the Sudanian and Sahelian savannas and is widely cultivated in agroforestry parklands across West Africa (Hall *et al.,* 1996). Its nuts, processed into butter, constitute an important source of dietary fat in the region and are also used in cosmetic and chocolate industries worldwide (Elias and Carney, 2007). An estimated 18.4 million people, mostly women, depend on its harvesting, processing, and marketing in sub-Saharan Africa (Naughton, Lovett and Mihelcic, 2015). The shea value chain is an essential activity for rural women, providing them with income in a context where access to productive resources (land, credit, training) remains limited (Elias and Carney, 2007).

Several studies have documented the sensitivity of shea to climatic variation. Bondé *et al.,* (2019) showed that interannual variability in fruiting is significantly higher in the arid zones of Burkina Faso (coefficient of variation = 152.25% in the Sahelian zone versus 130.46% in the Sudanian zone), indicating increased vulnerability of the species in the hottest and driest regions. Climate models predict a significant reduction in suitable shea habitats in West Africa. Dimobe *et al.,* (2020) estimate a reduction of 12% (RCP4.5) to 13% (RCP8.5) in suitable areas in Burkina Faso by 2070. In Togo, Atakpama *et al.,* (2022) project a decline in highly suitable areas of between 6.41% (RCP4.5) and 26.03% (RCP8.5) by 2055. These results, although varying by scenario and region, converge toward an increased vulnerability of the species, which could compromise the sustainability of the shea value chain in the medium term. Gadedjisso-Tossou *et al.,* (2021) demonstrated a significant increase in maximum temperatures in Kara, Niamtougou, and Mango between 1977 and 2012, with increases reaching 0.32°C per decade in Mango. Yao *et al.,* (2023) confirmed an increase in minimum and maximum temperatures in the Savanes region between 1981 and 2019, accompanied by an annual increase in rainfall in Dapaong (5.50 mm/year) but a decrease in Mango (-0.93 mm/year). Despite these documented trends, few studies have specifically examined the impacts of climate change on shea production in Togo, and to our knowledge, none has analyzed the perceptions of local stakeholders in this sector.

Taking local perceptions into account is essential for understanding vulnerability and designing adaptation strategies suited to on-the-ground realities (Mertz *et al.,* 2009). Ayanlade *et al.,* (2017) showed that farmers' perceptions in southwestern Nigeria largely align with meteorological data, with a 67% concordance rate and a significant correlation between farming experience and adaptive capacity ($r = 0.60$, $p < 0.05$). Ganni Mampo *et al.,* (2025) confirmed in Benin that 71% of farmers correctly perceive hydroclimatic variations, with a positive correlation between age ($r = 0.09$, $p = 0.04$), experience ($r = 0.19$, $p < 0.01$), and hydroclimatic knowledge. Moreover, the high proportion of women in the shea sector (Elias and Carney, 2007) calls for a gender-based analysis, as women are both the main actors in the sector and the most vulnerable to climate hazards due to unequal access to productive resources (Osman and Ayanlade, 2024).

In this context, the present study pursues three objectives: (i) to characterize the perception of climate change and associated risks among shea nut producers and collectors in the Savanes and Kara regions; (ii) to assess the perceived impacts on phenology, yields, and nut quality; and (iii) to analyze the adaptation strategies implemented and their perceived effectiveness. These three dimensions correspond respectively to exposure, sensitivity, and adaptive capacity, the components of the vulnerability framework used in this study and formalized by the IPCC (IPCC, 2023).

This exposure-sensitivity-adaptive capacity triptych is drawn directly from Adger (2006) and Turner *et al.,* (2003); the IPCC's Sixth Assessment Report (IPCC, 2023) reframes climate risk as a function of hazard, exposure, and vulnerability, with the latter breaking down into sensitivity and adaptive capacity. The two framings remain fundamentally compatible.

Materials and Methods

Study area

The study was conducted in two major shea-producing regions (*Vitellaria paradoxa*) in Togo: the Savanes region and the Kara region. These two areas are located in the northern part of the country, under a Sudanian climate with a single dry season and a single rainy season, in contrast to the Guinean climate with two rainy seasons that characterizes southern Togo (Atakpama *et al.,* 2022). Rainfall follows a unimodal pattern, with the rainy season extending from May to October (Gadedjisso-Tossou, Adjegan and Kablan, 2021; Yao *et al.,* 2023). In the Savanes region, long-term average annual rainfall reaches approximately 1041 mm in Mango and 1080 mm in Dapaong (Yao *et al.,* 2023), while in the Kara region, the Kara and Niamtougou stations record higher average annual rainfall of 1315 mm and 1364 mm, respectively (Gadedjisso-Tossou, Adjegan and Kablan, 2021). A total of eight prefectures were surveyed: Cinkassé, Kpendjal-Ouest, Oti-Sud, and Tandjouaré in the Savanes region; Binah, Dankpen, Doufelgou, and Kéran in the Kara region. Figure 1 shows the geographic location of the study area.

Data collection

Data collection took place from October to December 2025 in two successive phases, using a mixed-methods approach combining individual quantitative surveys and group discussions (Creswell and Clark, 2007; Zoundji *et al.,* 2017).

Individual survey

Sampling

The overall sample size was determined using Cochran's formula (1977):

$$n = \frac{Z^2 \times p(1-p)}{e^2} \quad (1)$$

Where n is the sample size, Z = 1.96 is the critical value at the 95% confidence level, p is the estimated proportion of the population presenting the characteristic under study (0.5 when no precise value is available), and e = 0.05 is the tolerated margin of error. Applying this formula gives

n = 384.16, rounded to 400 to cover the entire shea butter value chain (producers/collectors, processors, and traders).

The sample was distributed between the two regions using proportional stratification based on the number of households involved in shea production, according to data from the 2024-2028 Shea Sector Investment Action Plan (CIFKAT, 2023): 248 stakeholders in the Savanes region (62%) and 152 in the Kara region (38%). Within each region, prefectures and villages were selected in collaboration with local agricultural services. Within each village, respondents were identified and recruited through local agricultural advisors who maintain a database of producers and collectors.

This article focuses on the production/collection segment, which concerns 274 of the 400 stakeholders surveyed (68.5%). This figure falls within the range of reference studies in West Africa, n = 280 (Ayanlade, Radeny and Morton, 2017) and n = 421 (Mertz *et al.,* 2009). A complementary analysis covering the entire shea value chain (production, processing, and marketing) will be the subject of a separate publication. The 274 producers/collectors were not sampled separately: during the survey of the 400 value-chain stakeholders, each respondent was classified according to the activity they carried out at the time of the interview (production/collection, processing, or marketing); the 274 producers/collectors correspond to all individuals in the initial sample engaged in production and collection as a primary or secondary activity. The sub-sample targets individual producers and collectors active in the value chain, regardless of their status within the household, making the individual, rather than the household, the unit of observation. In the Savanes and Kara regions, shea is overwhelmingly a wild tree in agroforestry parklands, neither planted nor individually owned, which explains why nut collection does not follow a gendered land-ownership logic.

Data collection

A structured questionnaire was administered using the KoboCollect application, which enabled offline data collection in rural areas, geolocation of surveys, and automated data transmission, thereby reducing data-entry errors compared with paper forms (Aryal *et al.,* 2023). The questionnaire covered: (i) sociodemographic characteristics, (ii) perception of climate change, (iii) impacts on phenology, and (iv) impacts on yields and nut quality. Within the exposure-sensitivity-adaptive capacity framework used in this study, sensitivity is not measured as an intrinsic property of the production system but is operationalized through the impacts perceived and reported by respondents on phenology, yields, and nut quality; exposure corresponds to the identified climate risks and their perceived severity, and adaptive capacity to the strategies implemented and their perceived effectiveness. Before administering the questionnaire, the oral consent of each respondent was systematically sought; in case of refusal, the interview was not conducted and the person was thanked without further solicitation. Enumerators received training and conducted simulations before fieldwork to minimize collection bias. Enumerators were selected by locality based on their command of the local language. Interviews were conducted in the local language. The severity scale (1 to 5) and the interview guide questions were orally translated by enumerators at the time of collection, without a formal back-translation procedure to verify semantic equivalence between French and the local languages; this constitutes a methodological limitation to be considered in future surveys.

The perceived variation in nut harvest was collected in three steps: a closed question (“Do you consider that the quantity of shea nuts you harvest annually has varied over the past 10 years?”; possible answers: Yes / No / Don't know); if the answer was positive, a question on the direction of this change (Decreased / Increased / Become more unpredictable); then an open quantification question specifically covering the past 10 years, to limit recall bias (“Can you estimate this variation over the past 10 years?”, in the form “before I harvested X but now I harvest Y”). The open-ended answers were then converted into a percentage variation by the research team using the formula ((X-Y)/X) × 100, to allow for the quantitative statistical analysis presented below.

Group discussions

Eight group discussions (one per prefecture) were organized following the specific-group vulnerability analysis method, adapted from the work of Boureima *et al.,* (2012). Each group discussion brought together 15 to 20 participants. A structured interview guide directed the sessions around two components. The first concerned the participatory assessment of climate risk severity, rated on a severity scale from 1 (negligible) to 5 (extreme). The second concerned adaptation strategies, measured by a perceived effectiveness (PE) score. For each identified climate risk, stakeholders assessed the effectiveness of their current adaptation strategies on a scale of 1 to 5: 1 = negligible effectiveness, 2 = low effectiveness, 3 = moderate effectiveness, 4 = high effectiveness, 5 = excellent effectiveness.

When several strategies were used for the same risk, each strategy received its own PE score. Severity and perceived-effectiveness scores were established by consensus within each group, facilitated by the research team: for each risk and then each strategy, the facilitator proposed an initial rating open to group discussion, gathered dissenting views, and reformulated the question until no objection was raised, without resorting to a formal vote or an average of individual ratings; this approach, common in participatory vulnerability assessments, does not rule out the possibility that one or more dominant voices influenced the final rating within groups of 15 to 20 participants.

Statistical analysis methods

Data from individual questionnaires were processed using Microsoft Excel 2021. Descriptive statistics (frequencies, proportions, means ± standard deviations) were calculated for all variables. The remaining analyses were performed using R software version 4.5.2 (R Core Team, 2025), using the following packages: stats (v4.5.2, base R) for the Kruskal-Wallis test and the Chi-square test, FSA (v0.10.1) for Dunn's post-hoc test with Bonferroni correction, rcompanion (v2.5.4) for determining homogeneous grouping letters, vcd (v1.4-13) for calculating Cramér's V, readxl (v1.4.5) for data import, dplyr (v1.2.0) for data manipulation, and ggplot2 (v4.0.2) for producing figures. A Spearman rank correlation (Spearman, 1904) was calculated, on an exploratory basis, between the exposure index and the average perceived decline in production by prefecture ($n = 8$), using the cor.test function of the stats package, which natively handles the ties present in these two variables.

Two complementary methods were used:

- For the variation in nut production decline, the non-parametric Kruskal-Wallis test (1952) was applied.

Pairwise comparisons were performed using Dunn's post-hoc test (1964) with Bonferroni correction (Armstrong, 2014). The significance threshold was set at $\alpha = 0.05$.

- Chi-square test and Cramér's V coefficient: For each sociodemographic variable (sex, education level, and years of experience) and prefecture linked to the main perceived climate risk, a Pearson Chi-square test (1900) was performed and Cramér's V coefficient was calculated. The significance threshold was set at $\alpha = 0.05$. The strength of the association was interpreted according to Cohen's thresholds (1988). The "flooding" category, very weakly represented in the sample (less than 1% of observations, absent in seven of the eight prefectures), has expected cell counts below the threshold generally recommended for the validity of the Chi-square test (expected count ≥ 5); it was nonetheless retained in the contingency table for descriptive purposes, as the overall observed association is driven mainly by the three most frequent risk categories (irregular rainfall, strong winds, and bushfires). For the same reasons, the "higher education" category (1.09% of respondents) and the "more than 40 years" professional-experience category (0.36%) also have expected cell counts below the recommended validity threshold; the Chi-square test results should therefore be interpreted with the same caution. Fisher's exact test, less sensitive to low expected cell counts, was performed for each of the four variables (exact method for sex, education level, and professional experience; Monte Carlo simulation method, B = 10,000 replications, for prefecture, given the number of crossed categories) to verify the robustness of the Chi-square results against low expected cell counts.

The value chain's exposure index (%) to climate risks is calculated from severity scores (scale of 1 to 5) collectively assigned by the participants of each group discussion, according to the formula:

$$\textbf{\textit{exposure index}}\ (\%) = \left[\sum(\textbf{\textit{scores}})/\boldsymbol{n_{risks}} \times \mathbf{5}\right] \times \mathbf{100} \qquad (2)$$

Where n_{risks} represents the number of climate risks assessed and 5 the maximum severity score. Since a score of 0 is assigned to any risk not identified by the group, the index reflects both the severity and the diversity of perceived risks in each prefecture; it should therefore be interpreted as a combined measure rather than a pure measure of intensity.

This aggregation makes the construction of the index transparent and facilitates inter-regional comparisons. The method of Boureima *et al.,* (2012) guided the entire participatory process, from group selection to the interpretation of vulnerability matrices. This index results from a single consensus score per prefecture, established by a single discussion group (n = 1 per prefecture); it therefore constitutes a descriptive measure of perceived exposure, not statistically testable, and the differences observed between prefectures should be read as indicative rather than as significant differences.

Results and Discussion

Sociodemographic characteristics of respondents

Of the 274 shea nut producers and collectors surveyed, women were largely predominant, representing 88.32% of the sample versus 11.68% men (Table 1). The age distribution showed that the 25-45 age group (50%) and the 46-60 age group (48.54%) accounted for the bulk of respondents. The extreme age groups (under 25 and over 60) were very weakly represented, at 0.73% each.

Regarding education level, 63.87% of respondents had received no formal schooling, 24.82% had attended primary school, 10.22% secondary school, and 1.09% higher education. The experience bracket of 10 to 20 years was the most represented (50.73%), followed by less than 10 years of experience (30.66%) and 21 to 40 years (18.25%). Across the whole sample, 45.26% of respondents were members of a cooperative, while 54.74% were not.

Assessment of perceptions of climate change and risks

Nearly all respondents (99.27%) reported observing changes in climate in their area over the past 30 years.

Irregular or poorly distributed rainfall is the main climate risk cited by 42.34% of respondents overall (Table 2), followed by strong winds (33.94%), bushfires (23.36%), and flooding (0.36%). Perceptions showed strong spatial heterogeneity. In Dankpen, 93.75% of respondents identified irregular rainfall as the main hazard.

In Cinkassé (65.96%) and Tandjouaré (53.49%), strong winds predominate. Bushfires are the priority risk in Doufelgou (94%) and Oti-Sud (63.16%).

Assessment of perceived impacts of climate change on trees, phenology, and production

As sample sizes vary considerably from one prefecture to another (from 15 in Binah to 57 in Oti-Sud), the results presented below (sections 3.3.1, 3.3.2, and 3.3.3) are descriptive in nature, with no inferential statistical test applied to these reported impacts.

Perceived impacts on shea trees

All identified risks lead to increased shea tree mortality, reported by 69.83% to 75.27% of respondents depending on the type of risk (Table 3). Bushfires have the most severe impacts: 80.6% of exposed producers reported burned trees, 70.15% increased mortality, and 68.66% slower growth. Irregular rainfall is associated with a high prevalence of disease and pests, reported by 34.48% of respondents, with increased mortality (69.83%) and slower growth (64.66%). Strong winds lead to increased tree mortality for 75.27% of producers and degrade the overall appearance of trees in 58.06% of cases.

Perceived impacts on phenology

93.5% of respondents reported changes in flowering. The most frequent disturbances were flower abortion (18.60% to 100% depending on the prefecture) and less abundant flowering (62.79% to 100%) (Table 4). A shortening of the flowering period was observed in several prefectures, notably in Binah (67%), where the proportion is highest. These phenological disturbances have direct consequences on fruit set and yields.

Perceived impacts on fruiting

93.8% of respondents reported disturbances in fruit set. The most frequent manifestations were a reduction in fruit number (reported by 66.67% to 100% of respondents depending on the prefecture), smaller fruit formation (20.0% to 93.75%), premature fruit drop before full maturity (41.03% to 100%), and irregular ripening (5.13% to 93.33%) (Table 5). In Doufelgou, 40% of respondents also reported an increased presence of insects on the nuts.

Perceived yield variation

Overall, 93.1% of respondents indicated that the quantity of nuts harvested had varied over the past 10 years. Among these, 96.9% reported a decline in yields and 3.1% a more irregular production. This decline was near-unanimous in most prefectures (100% in Binah, Cinkassé, Kpendjal-Ouest, and Oti-Sud). In Doufelgou, 43% of respondents reported irregularity rather than a significant decline.

The overall average perceived decline in production was 37.6 ± 13.0%. The Kruskal-Wallis test revealed a significant difference among the eight prefectures ($H (7) = 15.715$; $p = 0.028$). The associated effect size, calculated using the formula $\varepsilon^2 = H / (N - 1)$ (Tomczak and Tomczak, 2014), with $N = 240$ usable observations (number of people who reported a yield decline), is 0.066, corresponding to a small-to-moderate effect according to Cohen's thresholds (1988). Dunn's post-hoc test with Bonferroni correction, applied to the 28 possible pairwise comparisons between prefectures, did not identify any significantly distinct pair at the 0.05 threshold. The comparison closest to this threshold contrasts Binah (43.2 ± 14.3%) with Doufelgou (23.0 ± 14.6%) ($Z = 3.099$; $p = 0.054$), without reaching it.

This discrepancy between a significant global test and the absence of a significant pair after correction is explained by the stringency of the Bonferroni correction applied to a large number of comparisons, combined with the small sample size in Doufelgou (6 of 16 respondents reporting a decline; see the Study Limitations section). Statistically, the eight prefectures therefore belong to a single homogeneous group. The mean values of the seven other prefectures, Kéran (43.4 ± 13.3%), Tandjouaré (38.8 ± 13.6%), Oti-Sud (38.8 ± 12.2%), Dankpen (36.9 ± 10.1%), Kpendjal-Ouest (36.4 ± 14.9%), and Cinkassé (35.2 ± 13.0%), fall between these two extremes with no difference confirmed by the post-hoc test (Figure 2). The descriptive gap observed in Doufelgou remains notable but should be interpreted as a trend, not as a statistically established difference.

Perceived change in nut quality

A decline in quality is widely reported. A reduction in nut size is mentioned by 74.5% to 100% of respondents in all prefectures, except Doufelgou (6%). Drier nuts were reported by 12.5% to 93.3% of respondents depending on the prefecture, and increased difficulty shelling nuts by 12.5% to 79.2%, which adds to the workload of women collectors and reduces the market value of processed nuts.

Assessment of sociodemographic and geographic determinants of perceived risk

As indicated in the methods, the “flooding” category, as well as the “higher education” and “more than 40 years of experience” categories, have expected cell counts below the threshold recommended for the validity of the Chi-square test, which calls for the following results to be interpreted with this caveat in mind. The Chi-square test revealed that prefecture is the only determinant significantly associated with perceived climate risk ($\chi^2 = 200.4$; df = 21; $p < 0.001$; Cramér's V = 0.494) (Table 6), indicating a strong association according to Cohen's thresholds (1988). Sex ($\chi^2 = 4.3$; df = 3; p = 0.234; V = 0.125), education level ($\chi^2 = 8.4$; df = 9; p = 0.490; V = 0.101), and professional experience ($\chi^2 = 3.6$; df = 9; p = 0.936; V = 0.066) have no statistically significant effect on perceived risk. (These three variables are marked ‘ns’, for not significant, in Table 6) The lack of a detected effect for sex should be interpreted with caution given the small number of men in the sample (n = 32 out of 274), which limits the statistical power of the test to detect a real difference between sexes. Fisher's exact test confirms the Chi-square test results for all sociodemographic variables tested: sex (p = 0.254), education level (p = 0.353), and years of experience (p = 0.968) are not associated with perceived climate risk, while prefecture is strongly associated ($p < 0.0001$, value estimated by Monte Carlo simulation, B = 10,000).

These results indicate that the perception of climate risk is structured by respondents' geographic situation rather than by their individual characteristics. The prefecture of residence determines exposure to local hazards, which explains the strength of this association.

Assessment of exposure of the shea production/collection segment to climate risks

Exposure varies by prefecture (Table 7), based on a single consensus score established by one discussion group per prefecture (n = 1); these values are therefore presented here for illustrative purposes, to qualitatively situate prefectures relative to one another, and not as statistically comparable measures. Tandjouaré has the highest index (76%). Cinkassé and Binah follow, each with 72%. Oti-Sud reaches 64%. Kéran stands at 56%. Kpendjal-Ouest and Dankpen show 52% and 48%, respectively. Doufelgou ranks last with 48%, the least exposed prefecture. As the index is based on a single consensus score per prefecture, these differences should be read as descriptive rather than as statistically tested differences.

Strong winds dominate everywhere. They reach the maximum level, 5/5, in Oti-Sud and Tandjouaré. Elsewhere, they remain high, at 4/5. No prefecture is spared. Drought follows, with scores between 3 and 4 where the risk was identified. It reaches 4/5 in Cinkassé, Tandjouaré, and Binah. Heat waves vary more.

They reach 4/5 in Cinkassé and Oti-Sud, versus 1/5 in Kpendjal-Ouest and Doufelgou. Poorly distributed rainfall remains present in all prefectures, between 2 and 4, peaking in Tandjouaré and Binah. Flooding shows the lowest scores, between 2 and 3, and this risk was not identified in Dankpen and Doufelgou.

Strong winds cause premature flower and fruit drop, uprooting of shea trees, and destruction of stocks. Drought and irregular rainfall reduce yield and degrade nut quality. Heat waves promote nut blackening. Flooding causes leaching and rotting of the nuts.

A Spearman rank correlation between the exposure index by prefecture (Table 7) and the average perceived decline in production by prefecture (n = 8) was calculated on a purely descriptive basis ($\rho = 0.40$). This value is not accompanied by a formal hypothesis test: with n = 8 prefectures and an exposure index based on a single, non-replicated consensus score per prefecture, an inferential test would give a false impression of statistical rigor to a comparison that remains, by construction, descriptive.

Assessment of current adaptation strategies and their perceived effectiveness

The adaptation strategies identified during group discussions ranged from structural measures to ritual and religious practices (Table 8). In response to strong winds, strategies vary according to the nature of the intervention. Reinforcing the roofs of storage buildings scores best, with high perceived effectiveness in Oti-Sud (PE = 4) and moderate scores in Binah and Doufelgou (PE = 3). Taking shelter during windy episodes, reported in Tandjouaré, reaches intermediate effectiveness (PE = 2). Conversely, strategies based on reforestation or tree planting, reported in Kéran and Cinkassé, obtain the lowest score (PE = 1), reflecting their limited short-term effectiveness.

In response to irregular rainfall, responses remain largely spiritual in nature. Ancestor ceremonies, reported in Dankpen, Kpendjal-Ouest, and Tandjouaré, obtain a consistent score of 3/5. Religious and traditional prayer, mentioned in Doufelgou and Oti-Sud, reaches a more modest score (PE = 2). In Kéran, responses combine reforestation and regulation of tree cutting, with low-to-moderate scores (PE = 1 to 2), confirming the limited perceived technical room for maneuver in the face of this hazard.

In response to flooding, only one strategy is reported, in Kpendjal-Ouest: the temporary suspension of collection in affected areas, considered of low effectiveness (PE = 1).

Taken together, these results confirm a clear contrast between structural strategies, particularly roof reinforcement, which obtain the highest scores, and spiritual or reforestation-based strategies, which remain perceived as of limited effectiveness against water-related hazards.

The results presented above should be interpreted in light of the exposure-sensitivity-adaptive capacity framework introduced earlier, which draws not only on the IPCC but also on the foundational literature on the vulnerability of socio-ecological systems, notably Adger (2006) and Turner *et al.,* (2003). The high perceived exposure, the demonstrated sensitivity of shea to climate hazards, and the limited effectiveness of the adaptation strategies observed in this study correspond respectively to these three components.

A near-unanimous perception, consistent with sub-regional trends

This near-unanimous recognition rate (99.27%) exceeds the proportions documented in comparable contexts in West Africa. Mertz *et al.,* (2009) reported recognition rates ranging from 74% to 93% depending on the Sahelian zones studied. Ayanlade *et al.,* (2017) observed that 67% of farmers in southwestern Nigeria perceived recent climate changes.

The predominance of rainfall irregularity among perceived risks is consistent with the hydroclimatic intensification observed in semi-arid tropical regions. Panthou *et al.,* (2018), using daily rainfall data covering the Sahel since 1950, demonstrate that this intensification is indeed underway in the region. It is characterized by a decrease in the number of rainy days, combined with an increase in rainfall intensity when it does occur. This intensification exacerbates water stress on vegetation between rainfall episodes, consistent with the observations of shea nut producers in Northern Togo. Strong winds and bushfires complete this spectrum of perceived hazards: stakeholders identify a broader range of risks than rainfall variability alone.

Geography as the only significant determinant of perceived climate risk

This exclusive association with prefecture confirms that perceived risk is structured by local geographic exposure rather than by respondents' individual profiles. The main caveat concerns sex: the male sub-sample (n = 32) offers limited statistical power to detect a real difference between sexes, which calls for caution in reading the observed absence of effect.

This spatial heterogeneity, already detailed in the Results (Table 2), outlines a distinct risk profile for each prefecture: irregular rainfall in Dankpen, bushfires in Doufelgou and Oti-Sud, strong winds in Cinkassé and Tandjouaré, consistent with local agroecological conditions.

The absence of an experience effect (p = 0.936) contrasts with the findings of Ganni Mampo *et al.,* (2025) in northern Benin, who reported a significant positive correlation between farming experience and hydroclimatic knowledge (r = 0.19, p < 0.01). Several factors may explain this divergence. First, the sample of Ganni Mampo *et al.,* (2025) is composed of more than 90% men, whereas ours is composed of 88.32% women, representing two populations of agricultural stakeholders with potentially different dynamics of access to information. This high proportion of women reflects the actual division of labor in the shea value chain in Northern Togo, where the tree is overwhelmingly wild and not individually planted: nut collection there traditionally falls to women, regardless of land ownership. Second, the intensity and speed of the climate changes perceived in our study area could reduce the informational advantage generally associated with seniority, as disturbances are marked enough to be noticeable even to the least experienced stakeholders. This comparison nonetheless remains indicative: our Chi-square test assesses an association between experience categories and perceived-risk categories, whereas Ganni Mampo *et al.,* (2025) and Ayanlade *et al.,* (2017) report correlations between experience treated as a continuous variable and a knowledge or adaptation score; the two approaches are therefore not strictly equivalent.

The absence of an effect of formal education level ($p = 0.490$) partly agrees with the observations of Ganni Mampo *et al.,* (2025), who found a slight negative influence of formal education on hydroclimatic knowledge in northern Benin. These authors emphasize the importance of knowledge acquired through prolonged interaction with the local environment rather than through formal education. However, this absence of effect does not mean that education is unimportant; rather, it suggests that, in the specific context of the shea value chain, local knowledge remains the main source of information on climate variations and that extension programs should build on this knowledge rather than seek to replace it.

Marked perceived phenological and productive impacts

The phenological and productive disturbances, nearly universal yet highly heterogeneous across prefectures, are consistent with the demonstrated sensitivity of *Vitellaria paradoxa* to unfavorable climatic conditions. Bondé *et al.,* (2019), based on a four-year monitoring study of 212 trees across three climatic zones in Burkina Faso, show that interannual variability in fruiting of this species is significantly higher in the Sahelian zone (coefficient of variation of 152.25%) than in the Sudano-Sahelian (117.78%) or Sudanian (130.46%) zones, suggesting increased productive instability under the harshest climatic conditions, comparable to those of Northern Togo.

If confirmed, the average perceived decline of 37.6% would represent a substantial economic loss for households whose income depends on nut sales. Statistically, the eight prefectures form a single homogeneous group: the gap between Binah and Doufelgou, the most pronounced, does not reach the significance threshold after Bonferroni correction ($p = 0.054$).

Doufelgou shows the lowest average decline in the sample (23.0%) and stands out for the predominance of bushfires (93.75%) as the main perceived risk, unlike other prefectures where irregular rainfall or strong winds dominate. As an untested hypothesis, bushfires may affect tree integrity differently from risks that directly target flowering or fruiting; edaphic factors and management practices could also play a role, and only targeted field monitoring could disentangle these possibilities.

More broadly, the exposure index and the perceived production decline do not follow a consistent order from one prefecture to another. Tandjouaré, despite having the highest index in the sample (76%), records an average decline (38.8%) lower than that of Kéran (43.4%) or Binah (43.2%), which are nonetheless less exposed according to the index (56% and 72%). This lack of systematic correspondence is reflected in the weak correlation observed between the two variables ($\rho = 0.40$, descriptive only, see Results).

This dissociation is partly explained by the composite nature of the index, which aggregates five distinct climate risks (strong winds, drought, heat waves, flooding, poorly distributed rainfall), whereas the perceived production decline appears, in our results, more closely associated with a specific risk: irregular rainfall, which dominates in the prefectures showing the sharpest declines (Kéran, Binah), whereas in Tandjouaré, where strong winds reach their maximum score (5/5), high overall exposure is accompanied by a more moderate production decline. The exposure index should therefore be read as a tool for mapping the diversity and perceived intensity of climate risks, useful for prioritizing territorial interventions by type of risk, rather than as a direct predictor of the magnitude of the production decline.

These perception data present the limitations inherent to retrospective approaches. Local perceptions are generally more accurate for recent climate events but can be influenced by particularly significant extreme events that bias the recollection of general trends.

Consequently, these statements regarding 10-year production trends cannot substitute for objective yield monitoring, and the general trend should be interpreted as indicative rather than as a precise measure. Furthermore, future studies would be useful to measure the actual interannual variability of nut production in Northern Togo, in order to verify whether it follows a climatic gradient comparable to that observed in Burkina Faso by Bondé *et al.,* (2019).

Table.1 Sociodemographic characteristics of respondents by prefecture.

Variables	Categories	Percentage of respondents (%)								
		Binah	Cinkassé	Dankpen	Doufelgou	Kéran	Kpendjal-Ouest	Oti-Sud	Tandjouaré	Total
Sample size (n)		***15***	***47***	***48***	***16***	***23***	***25***	***57***	***43***	***274***
Sex	Female	80.00	72.34	93.75	94.00	73.91	100.00	91.23	97.67	**88.32**
	Male	20.00	27.66	6.25	6.00	26.09	0.00	8.77	2.33	**11.68**
Age	< 25 years	0.00	0.00	0.00	12.00	0.00	0.00	0.00	0.00	**0.73**
	25-45 years	67.00	53.19	43.75	50.00	78.26	48.00	50.88	32.56	**50.00**
	46-60 years	33.00	44.68	56.25	38.00	21.74	52.00	47.37	67.44	**48.54**
	> 60 years	0.00	2.13	0.00	0.00	0.00	0.00	1.75	0.00	**0.73**
Education level	None	33.00	87.23	79.17	31.00	26.09	84.00	64.91	51.16	**63.87**
	Primary	53.00	8.51	6.25	62.00	56.52	8.00	28.07	27.91	**24.82**
	Secondary	13.00	4.26	10.42	6.00	17.39	8.00	5.26	20.93	**10.22**
	Higher	0.00	0.00	4.17	0.00	0.00	0.00	1.75	0.00	**1.09**
Experience in the field	< 10 years	0.00	36.17	20.83	38.00	39.13	72.00	40.35	2.33	**30.66**
	10 - 20 years	100.00	38.30	33.33	50.00	60.87	28.00	45.61	81.40	**50.73**
	21 - 40 years	0.00	23.40	45.83	12.00	0.00	0.00	14.04	16.28	**18.25**
	> 40 years	0.00	2.13	0.00	0.00	0.00	0.00	0.00	0.00	**0.36**
Cooperative member	No	100.00	87.23	47.92	6.00	21.74	56.00	54.39	46.51	**54.74**
	Yes	0.00	12.77	52.08	94.00	78.26	44.00	45.61	53.49	**45.26**

Table.2 Main perceived climate risk affecting shea nut production and collection (%).

Prefecture	Flooding	Bushfires	Irregular or poorly distributed rainfall	Strong winds
Binah	0.00	7.00	47.00	47.00
Cinkassé	0.00	0.00	34.04	65.96
Dankpen	0.00	6.25	93.75	0.00
Doufelgou	0.00	94.00	6.00	0.00
Kéran	0.00	17.39	47.83	34.78
Kpendjal-Ouest	4.00	8.00	40.00	48.00
Oti-Sud	0.00	63.16	15.79	21.05
Tandjouaré	0.00	6.98	39.53	53.49
Overall total	**0.36**	**23.36**	**42.34**	**33.94**

Table.3 Perceived effects of climatic risks on the physical appearance of the tree (%)

Main risk	Increased mortality	Diseases/parasites (e.g., African mistletoe)	Slowed growth	General tree appearance	Burnt tree
Bushfires	70.15	13.43	68.66	65.67	80.60
Irregular or poor rainfall distribution	69.83	34.48	64.66	56.90	27.59
Strong winds	75.27	12.90	55.91	58.06	20.43

Table.4 Perceived changes in shea flowering (%)

Prefecture	Shorter	Flower abortion	Later	Less abundant
Binah	67.00	100.00	73.00	100.00
Cinkassé	27.66	100.00	12.77	97.87
Dankpen	6.25	95.83	31.25	66.67
Doufelgou	0.00	75.00	0.00	75.00
Kéran	20.83	91.67	50.00	66.67
Kpendjal-Ouest	20.00	92.00	52.00	68.00
Oti-Sud	17.54	75.44	50.88	71.93
Tandjouaré	25.58	18.60	51.16	62.79

Table.5 Perceived changes in shea fruiting (%)

Prefecture	Fewer fruits	Smaller fruits	Irregular ripening	Early fruit drop	Other
Binah	93.00	93.00	93.00	100.00	0.00
Cinkassé	87.23	65.96	72.34	85.11	0.00
Dankpen	89.58	93.75	6.25	54.17	0.00
Doufelgou	100.00	20.00	40.00	60	40.00
Kéran	66.67	50.00	45.83	91.67	12.50
Kpendjal-Ouest	70.83	79.17	33.33	83.33	0.00
Oti-Sud	84.21	70.18	45.61	68.42	0.00
Tandjouaré	79.49	51.28	5.13	41.03	0.00

Table.6 Results of Chi-square, Cramér's V, and Fisher's tests between sociodemographic and geographic variables and perceived climate risk.

Variable	Chi-square	df	p-value	Significant	Cramér's V	Fisher p-value	Fisher method
Prefecture	200.4	21	< 0,001	***	0.494	1.00E-04	Simulated (Monte Carlo, B = 10,000)
Sex	4.3	3	0.234	ns	0.125	0.254	exact
Education level	8.4	9	0.490	ns	0.101	0.353	exact
Years of experience	3.6	9	0.936	ns	0.066	0.968	exact

(*** p < 0.001; ns: not significant)

Note. The "Flooding" column has expected cell counts below the threshold of 5 recommended for the validity of the Chi-square test: 2 of 8 cells (25%) for sex, 7 of 16 cells (43.8%) for education level, and 7 of 16 cells (43.8%) for professional experience. Fisher's exact test, less sensitive to low cell counts, is reported in addition for each variable.

Table.7 Perceived severity matrix of climate risks by prefecture

Climate risks	Cinkassé	Kpendjal-Ouest	Oti-Sud	Tandjouaré	Dankpen	Doufelgou	Kéran	Binah
Heat waves	4	1	4	3	4	1	3	3
Drought	4	3	3	4	0	4	0	4
Strong winds	4	4	5	5	4	4	4	4
Flooding/heavy rainfall	2	2	2	3	0	0	3	3
Poor rainfall distribution	4	3	2	4	4	3	4	4
Exposure index (%)	**72**	**52**	**64**	**76**	**48**	**48**	**56**	**72**

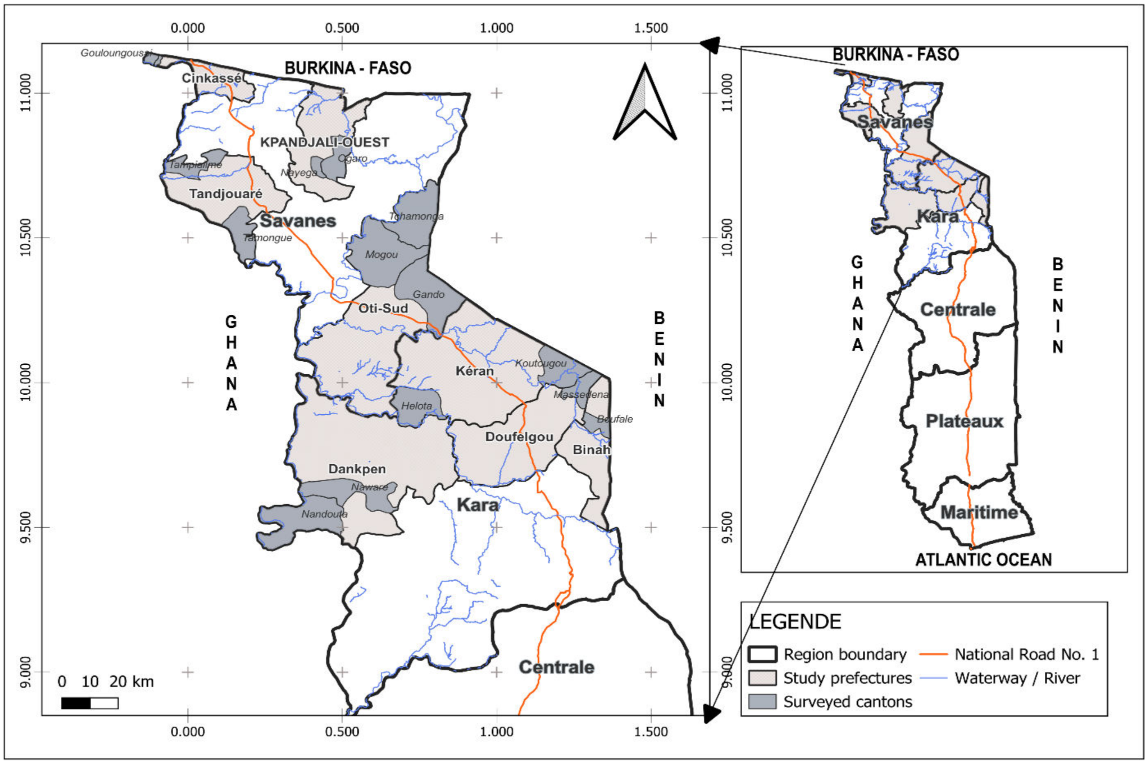
1 = negligible severity, 5 = extreme severity. A score of 0 indicates a risk not identified by stakeholders in the prefecture concerned. Single consensus score per prefecture (n = 1), not replicated; to be read as descriptive.

Table.8 Current adaptation strategies and perceived effectiveness (PE) scores

Prefecture	Climate hazard	Adaptation strategy	PE
Binah	Strong winds	Weighting roofs with stones	3
Cinkassé	Strong winds	Tree planting (non-functional)	1
Dankpen	Irregular rainfall	Ceremony to the ancestors	3
Doufelgou	Strong winds	Weighting roofs	3
	Irregular rainfall	Religious and traditional prayer	2
Kéran	Strong winds	Reforestation (young seedlings)	1
	Irregular rainfall	Reforestation / logging regulation	1
		Regulation of tree cutting	2
Kpendjal-Ouest	Flooding	Temporary halt of collection	1
	Irregular rainfall	Ceremony to the ancestors	3
Oti-Sud	Strong winds	Fleeing during collection / roof reinforcement	3
		Roof reinforcement (weighting roofs with stones or replacing sheet metal)	4
	Irregular rainfall	Religious and traditional prayer	2
Tandjouaré	Strong winds	Taking shelter during windy episodes	2
	Irregular rainfall	Ceremony to the ancestors	3

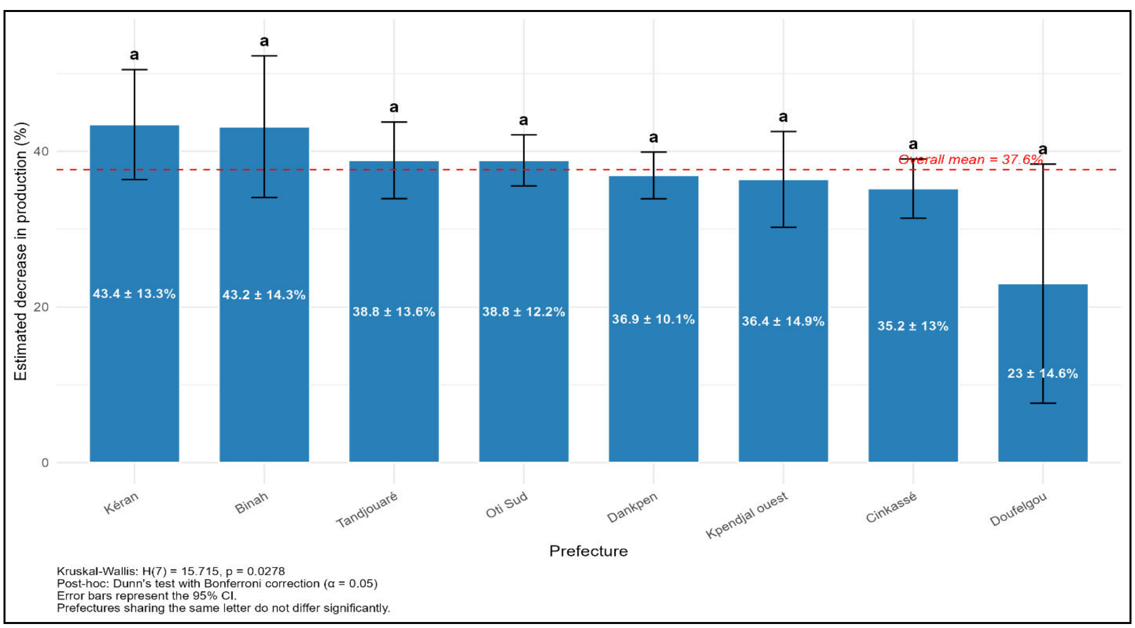
PE: perceived effectiveness score, 1 (very low) to 5 (very high)

Figure.1 Geographic location of the study area



Base map: (GADM, 2021); Produced by: Kotchadjo (2025)

Figure.2 Estimated decline in shea nut production by prefecture (%) over the past 10 years.



Bars represent means and error bars represent the 95% confidence interval. As the Dunn-Bonferroni post-hoc test ($\alpha = 0.05$) did not identify any significantly distinct pair of prefectures, all eight prefectures belong to a single homogeneous group. Kruskal-Wallis test: $H = 15.715$, $p = 0.028$.

These perceptions can be compared, on a qualitative basis, with measured climate trends already documented in the study area. Gadedjisso-Tossou *et al.,* (2021) established an increase in maximum temperatures in Kara, Niamtougou, and Mango between 1977 and 2012, reaching 0.32°C per decade in Mango, while Yao *et al.,* (2023) observed a contrasting evolution of rainfall in the Savanes region between 1981 and 2019, increasing in Dapaong (5.50 mm/year) but decreasing in Mango (-0.93 mm/year). These objective trends are consistent with growing climatic pressure on the shea value chain and corroborate, in their general direction, the perceptions reported by respondents. They do not, however, allow validation of the exact magnitude of the perceived production decline, owing to the lack of yield series measured over the same period and in the same localities. These climate data also come from stations and observation periods predating the present survey, with no weather data collection specific to this study nor geolocated at the level of the eight surveyed prefectures. The comparison therefore remains qualitative, unlike the approach of Ayanlade *et al.,* (2017), who directly compare farmers' perceptions with local meteorological data.

Differential effectiveness of adaptation strategies across hazard types

This contrast between structural strategies and reforestation-based strategies, already established in the Results (see section 3.6), is partly explained by local conditions. In Cinkassé and Kéran, poor soil quality, water scarcity, and the lack of post-planting follow-up limit the perceived effectiveness of reforestation, whereas roof reinforcement directly addresses the risk of strong winds.

The prevalence of ritual and religious practices in response to irregular rainfall, with perceived-effectiveness scores of 2 to 3, reflects a mismatch between perceived risk and available adaptation mechanisms. Similar adaptation mechanisms, combining indigenous and empirical knowledge, have been documented among Senegalese artisanal fishers by Mbaye *et al.,* (2016), who note a clear generational divide: younger fishers tend to move away from indigenous knowledge in favor of empirical knowledge acquired through modern equipment, whereas older fishers remain attached to it. A comparable pattern could exist among shea producers in Northern Togo, although this hypothesis was not directly tested in our study.

The strong representation of women in the sample exposes the structural vulnerability to climate hazards mainly among those involved in collection. Osman & Ayanlade (2024) showed, in a comparative study conducted in Ghana and Nigeria, that women farmers are more vulnerable to climate change than men and less likely to adopt climate-resilient practices due to unequal access to productive resources. This dynamic is consistent with the increased shelling difficulties and the reduction in nut size observed in several prefectures in our study, which directly adds to the workload of women producers without visible economic compensation. It should nonetheless be emphasized that this reading remains qualitative and contextual: the statistical test performed in this study did not reveal a direct effect of sex on the perception of climate risk ($\chi^2 = 4.3$; df = 3; $p = 0.234$; $V = 0.125$). The argument developed here therefore concerns the economic and operational vulnerability of women collectors in the face of already-perceived impacts, rather than a difference in risk perception between men and women.

Study limitations

Several limitations should be noted. The perceived production decline, estimated at 37.6%, is based on retrospective statements not validated by objective data, exposing it to recall bias, even though convergence across prefectures strengthens its plausibility. Statistical robustness varies considerably by prefecture, as discussed for Doufelgou in section 4.3. Recruitment through local agricultural advisors constitutes a convenience sample, which may underrepresent the most isolated and vulnerable producers. The exposure and perceived-effectiveness scores, derived from group discussions (8 prefectures, 15 to 20 participants), rest on a consensus that may have been influenced by dominant voices, and these groups had no formal representativeness, so the strategies reflect the positions of those present rather than a validated prefecture-wide consensus. The exposure index, based on a single consensus score per prefecture ($n = 1$), is descriptive and not statistically testable; furthermore, the list of risks identified in the group discussions differs from that of the individual survey, limiting comparability. A future study would benefit from cross-referencing this index with the severity scores collected individually in the quantitative survey, to obtain a measure of convergence, even partial, between the collective assessment and individual perceptions. Some categories have insufficient expected cell counts for the Chi-square test (see sections 2.3 and 3.4). Finally, the adaptation strategies remain self-reported and retrospective, with no longitudinal monitoring of their actual implementation or their effectiveness on production. Furthermore, the perceived production decline may also partly reflect non-climatic factors not isolated in this protocol, such as the aging of the tree stock, soil degradation, or changes in collection effort linked to market prices; the exclusive attribution of this decline to climate change should therefore be qualified.

In conclusion, this study points to an apparent gap, in the shea value chain of Northern Togo, between the intensity of perceived climate risks and the low effectiveness of the adaptation strategies currently available to address them, an observation that remains descriptive rather than statistically tested. This vulnerability is structured by local geography rather than by the individual characteristics of producers and collectors. The near-unanimous recognition of climate change, combined with severe phenological and productive disturbances, confirms the urgency of a response tailored to the specificities of each prefecture rather than a uniform regional approach, given a statistically significant but small-to-moderate prefecture effect ($\varepsilon^2 = 0.066$). The perceived decline in production should be read as a signal of perceived vulnerability rather than as a measure of climate impact isolated from all other factors. The exposure index does not directly predict this decline: it primarily serves as a risk-mapping tool, useful for guiding interventions according to the dominant hazard type in each prefecture.

The adaptation strategies currently implemented, whether rudimentary structural measures or ritual practices, are insufficient to offset the intensity of the observed climate hazards. This insufficiency calls for several courses of action. First, technical support interventions should be tailored to each prefecture according to the identified dominant risk, rather than designed as a generic program applicable to the entire study area. The needs of Doufelgou, exposed to bushfires, differ fundamentally from those of Dankpen, confronted with irregular rainfall. Second, reforestation strategies, whose perceived effectiveness remains low in Cinkassé and Kéran, require strengthened technical support focused on species selection, water management, and post-planting follow-up, rather than the simple distribution of seedlings. Third, given the female predominance in the sector, adaptation policies would benefit from specifically targeting women producers' access to technical and financial resources, a necessary condition for translating better knowledge of climate risks into effective capacity for action. The shea value chain, a pillar of the rural female economy in Togo, deserves priority in national and regional adaptation policies.

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Author Contributions

Kossi KOTCHADJO: Conceptualization, Methodology, Software, Validation, Formal Analysis, Data Curation, Writing – Original Draft Preparation, Visualization. Atti TCHABI: Conceptualization, Methodology, Validation, Writing – Review and Editing, Supervision. Komi AGBOKA: Conceptualization, Writing – Review and Editing, Supervision, Project Administration

Data availability

Anonymized individual-level data are deposited in an open repository, and the corresponding link is: https://doi.org/10.5281/zenodo.22200227

Declarations

Ethics approval and consent to participate Before any data were collected, all participants were fully informed of the study's objectives. Each participant provided informed consent prior to taking part in the surveys. No invasive procedures were involved in this study, and participation was completely voluntary.

Consent to Publish We, the authors, give our consent for the publication of this article and confirm that it is original, has been approved by all co-authors, and is not currently under consideration by any other journal.

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

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