



Perceived Climate Exposure, Agricultural Impacts and Food-System Vulnerability among Smallholder Farmers in Bong, Lofa and Nimba Counties, Liberia

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Abstract: Background: Climate risk is experienced by smallholder farmers through interacting environmental, production and food-system pathways, but household surveys can easily confuse perceived change with observed meteorological trends. This study assessed reported climate exposure, perceived agricultural impacts and perceived food-security impacts among smallholder farmers in three Liberian counties. Methods: A quantitative cross-sectional survey included 419 respondents from Bong (n = 142), Lofa (n = 100) and Nimba (n = 177). Three multi-item scales were examined using descriptive statistics, internal-consistency analysis, full-sample and response-quality sensitivity comparisons, county and gender tests, and HC3-robust multivariable regression. A sensitivity sample excluded 124 respondents who gave uniform answers across all 43 Likert items. Results: Full-sample means were 3.949 (SD 0.528) for climate awareness and perceived exposure, 3.989 (SD 0.523) for perceived agricultural impacts, and 4.012 (SD 0.523; n = 412) for perceived food-security impacts. Corresponding sensitivity means were 3.921, 3.977 and 4.011. County differences were substantial and persisted after sensitivity exclusion, whereas unadjusted gender differences were not statistically significant. In robust adjusted models, county, age and household size were associated with multiple perceived-impact outcomes; the models explained 24.2%-31.8% of outcome variance. Conclusions: Surveyed farmers widely reported climatic, agricultural and food-system stress, but the findings describe perceptions and associations rather than measured climate trends, yield losses or causal effects. Independent climate, crop and market records are required to validate magnitude and timing. The results support county-sensitive climate services, pest and soil-water management, market resilience and longitudinal monitoring.

Keywords: climate perception, agricultural impacts, food-system vulnerability, smallholder farmers, sensitivity analysis, Liberia

INTRODUCTION

Smallholder agriculture in sub-Saharan Africa is exposed to rainfall variability, heat, flooding, soil and water stress, pests, disease and market disruption. These hazards rarely operate independently. A delayed rainy season may alter planting dates, lower soil moisture, intensify pest pressure, raise production costs and reduce marketed surplus. Road damage and supply disruption can transmit the same shock through food prices and availability. Climate vulnerability is therefore produced through the interaction of environmental exposure, livelihood sensitivity and the resources and institutions that enable adaptation (Intergovernmental Panel on Climate Change [IPCC], 2022, 2023).

Liberia's agricultural economy remains strongly dependent on rain-fed smallholder production. National policy identifies resilient production, improved seed, sustainable land and water management, extension, market infrastructure and climate information as important development priorities (Republic of Liberia, 2021; Ministry of Agriculture, 2024). The World Bank (2024) similarly identifies increasing heat, erratic rainfall, flooding and weak readiness as development risks. These national assessments establish context, but they do not provide respondent-level evidence about how farming households interpret changing conditions in Bong, Lofa and Nimba Counties.

Farmer perceptions matter because decisions are made through interpreted experience. Producers respond to anticipated rain, remembered seasons, visible soil moisture, pest outbreaks, extension advice and household resource constraints. Perceptions can therefore influence planting, crop choice, input expenditure and adaptation even when they do not precisely reproduce an instrumental climate series. At the same time, cross-sectional perception surveys cannot estimate meteorological trends or causal yield effects. Treating self-reported awareness as observed climate change would exceed the evidence.

This study addresses that distinction by analysing three related but separate constructs: climate awareness and perceived exposure; perceived agricultural impacts; and perceived food-security impacts. It uses transparent response-quality sensitivity analysis because 124 of 419 respondents selected the same category across all 43 Likert statements. Rather than silently retaining or automatically deleting those cases, the study reports both the submitted full sample and a differentiated-response sensitivity sample.

The objectives were to: (1) describe the three perceived-impact constructs and their item profiles; (2) test whether aggregate findings were robust to exclusion of uniform response profiles; (3) compare outcomes across counties and respondent sex; and (4) estimate adjusted associations between the perceived-impact outcomes and measured demographic, farm and geographic characteristics. The study hypothesised no county or sex differences in the mean scale scores and no adjusted associations between respondent characteristics and the three outcomes.

CONCEPTUAL FRAMEWORK

The analysis draws on vulnerability and food-systems reasoning. Exposure refers to reported climatic and environmental stressors, sensitivity concerns perceived consequences for farming and livelihoods, and adaptive capacity concerns the assets, knowledge, services and institutional conditions through which households respond. The food-systems perspective extends the pathway beyond production: climate-related shocks may affect own-produced food, income, prices, transport, distribution, safety and stability. These pathways are analytically connected but should not be collapsed into a single causal index.

The expected sequence is perceived climatic exposure → perceived agricultural impact → perceived food-system impact. This sequence is a conceptual ordering, not temporal proof. All three constructs were measured from the same respondent at one interview, making common-method variance, recall, framing and response style plausible alternative explanations. Accordingly, the exploratory pathway estimates are used to describe covariance consistent with the framework, not to claim mediation or causal transmission.

MATERIALS AND METHODS

Study Design and Setting

The study used a quantitative cross-sectional household survey conducted among smallholder farmers in Bong, Lofa and Nimba Counties, Liberia. Fieldwork occurred from 30 July to 11 August 2025. The submitted electronic database contained 419 respondent records: 142 from Bong, 100 from Lofa and 177 from Nimba. No exact duplicate row was identified. The achieved sample was predominantly male (63.7%), and 92.4% identified farming as their primary occupation. These proportions describe the achieved sample; population inference requires documented selection probabilities and sampling weights.

Measures

Climate awareness and perceived exposure were assessed with 12 five-point Likert statements covering awareness, rainfall irregularity, drought, soil moisture, yield decline, pests and diseases, temperature, flooding, erosion and heavy winds. Perceived agricultural impacts were assessed with 14 statements covering planting changes, pests, weeds, crop failure, costs, produce loss, delayed planting, diseases, livestock, harvest, displacement, yield, soil fertility and crop disease. Perceived food-security impacts were assessed with 17 statements relating to scarcity, prices, markets, crop effects, availability, supply, distribution, income, instability, quality, safety, shortage, poverty, crop damage and pests. One positively worded item on being food secure requires directional caution and was not used to claim a perfectly unidimensional adverse-impact construct.

Data-quality and Sensitivity Protocol

A response audit found 124 respondents (29.6%) who used one response category across all 43 Likert items; 122 selected Agree throughout and two selected Strongly Agree throughout. Uniform responding does not by itself prove fabrication. It may reflect satisficing, misunderstanding, interview standardisation, data-entry processes or genuinely consistent views. The primary analyses retained all submitted records. Sensitivity analyses excluded the 124 flagged cases, producing $n = 295$ for the first two scales and $n = 288$ for the food-security-impact scale because of additional item missingness. The flagged profiles were concentrated among particular enumerators and counties. Enumerator assignment and county were strongly associated, creating potential geographic-administration confounding. County results are therefore presented as patterns in the achieved sample, not as pure contextual effects.

Statistical Analysis

For each scale, the analysis calculated the valid n , mean, standard deviation, 95% confidence interval and Cronbach's alpha. Item agreement combined Agree and Strongly Agree. County means were compared using one-way analysis of variance with eta-squared as an effect-size measure; male and female means were compared with Welch's t test. Full and sensitivity samples were reported side by side. HC3-robust ordinary least-squares models estimated adjusted associations with respondent sex, age-group midpoint, education, farming-experience midpoint, household-size midpoint, farm and enterprise variables, and county indicators. Robust confidence intervals reduce sensitivity to

heteroskedastic residuals but do not correct measurement error, omitted variables, common-method bias or the cross-sectional design. Statistical tests were two-sided, and interpretation considered estimates, confidence intervals, p-values and adjusted R^2 .

Ethics

Ethical approval was granted by the Njala University Research Ethics Committee on 2 March 2025 (reference NURE_123NC). Participation was voluntary and based on informed consent. No identifiable participant information is reported in this manuscript.

RESULTS

Scale Profiles and Sensitivity Analysis

Construct	Sample	n	Items	Mean	SD	Cronbach's α
Climate awareness/exposure	Full	419	12	3.949	0.528	0.885
Climate awareness/exposure	Sensitivity	295	12	3.921	0.622	0.883
Perceived agricultural impacts	Full	419	14	3.989	0.523	0.897
Perceived agricultural impacts	Sensitivity	295	14	3.977	0.618	0.895
Perceived food-security impacts	Full	412	17	4.012	0.523	0.921
Perceived food-security impacts	Sensitivity	288	17	4.011	0.618	0.920

Note: Values are reproduced from the verified thesis tables; percentages and model denominators are stated explicitly.

All three full-sample means were close to 4 on the five-point response scale and changed little after exclusion of uniform responders. The largest full-to-sensitivity mean difference was 0.028 for climate awareness/exposure. Internal consistency remained high in both analytical samples. These results indicate that broad endorsement of perceived stress was not solely produced by the uniform profiles, although high alpha may partly reflect similarly worded items and shared response method. For climate awareness/exposure, the most highly endorsed items concerned reduced soil moisture (90.7%), decreased crop yield (90.5%) and rising temperature (90.5%). Within perceived agricultural impacts, crop failure and poor harvest (90.9%), reduced harvest (90.7%), delayed planting (90.0%) and rapid spread of diseases and parasites (89.7%) were prominent. Food-system items most frequently endorsed included reduced income (92.8%), disrupted crop distribution (91.9%), effects on food availability (91.9%), reduced food quality (91.9%) and reduced food supply (91.4%). These are reported perceptions; the questionnaire did not measure crop-specific yield loss, income change or nutritional status.

County and Gender Comparisons

Outcome	Bong mean	Lofa mean	Nimba mean	F	p	η^2
Climate awareness/exposure	3.574	4.056	4.190	76.563	<0.001	0.269
Perceived agricultural impacts	3.636	4.068	4.227	68.462	<0.001	0.248
Perceived food-security impacts	3.742	4.050	4.208	37.054	<0.001	0.151

Note: Values are reproduced from the verified thesis tables; percentages and model denominators are stated explicitly.

Mean scores were lowest in Bong and highest in Nimba for every construct. County explained 15.1%-26.9% of full-sample variance. The same ordering persisted in the sensitivity sample, where eta-squared was 0.313 for climate awareness/exposure and agricultural impacts and 0.202 for food-security impacts. Nevertheless, county and enumerator effects cannot be separated cleanly in the submitted dataset, so the differences require independent field-team and observed-data validation.

Unadjusted male and female means were similar. For climate awareness/exposure, the means were 3.949 and 3.950 (Welch $t = -0.029$, $p = 0.977$); for agricultural impacts, 4.000 and 3.969 ($t = 0.562$, $p = 0.575$); and for food-security impacts, 4.021 and 3.997 ($t = 0.431$, $p = 0.667$). These results indicate insufficient evidence of mean sex differences, not proof that men and women experience identical exposure, decision-making power or adaptive capacity.

Adjusted Associations

Outcome	Adjusted predictor	B	Robust 95% CI	p
Climate awareness/exposure	Female respondent	0.119	0.020 to 0.219	0.019
Climate awareness/exposure	Age-group midpoint	0.006	0.001 to 0.011	0.012
Climate awareness/exposure	Household-size midpoint	0.015	0.002 to 0.027	0.020
Climate awareness/exposure	Lofa County	0.421	0.303 to 0.538	<0.001
Climate awareness/exposure	Nimba County	0.602	0.486 to 0.718	<0.001
Agricultural impacts	Age-group midpoint	0.007	0.002 to 0.011	0.004
Agricultural impacts	Educational level	0.036	0.002 to 0.070	0.039
Agricultural impacts	Household-size midpoint	0.020	0.007 to 0.033	0.003
Agricultural impacts	Lofa County	0.359	0.239 to 0.480	<0.001
Agricultural impacts	Nimba County	0.577	0.457 to 0.696	<0.001
Food-security impacts	Age-group midpoint	0.007	0.002 to 0.012	0.009
Food-security impacts	Farming-experience midpoint	0.017	0.007 to 0.026	<0.001
Food-security impacts	Household-size midpoint	0.019	0.006 to 0.032	0.005
Food-security impacts	Lofa County	0.158	0.033 to 0.283	0.013
Food-security impacts	Nimba County	0.419	0.296 to 0.542	<0.001

Note: Values are reproduced from the verified thesis tables; percentages and model denominators are stated explicitly.

The climate-awareness model explained 31.8% of variance (adjusted $R^2 = 0.307$), the agricultural-impact model 30.8% (adjusted $R^2 = 0.296$), and the food-security-impact model 24.2% (adjusted $R^2 = 0.229$). County indicators were the largest and most consistent adjusted terms. Age and household size were positively associated with all or most constructs. Education was positively associated with perceived agricultural impacts, while farming experience was positively associated with perceived food-security impacts.

The positive adjusted female coefficient in the awareness model contrasts with the null unadjusted sex comparison. This difference reflects covariate adjustment and should not be overinterpreted as a causal gender effect. The survey did not measure all dimensions of household control, information access, workload or exposure that would explain a gender pathway.

Exploratory Pathway Evidence

An exploratory cross-sectional decomposition was consistent with the conceptual sequence: awareness/exposure was positively associated with agricultural impact ($a = 0.830$), and agricultural impact was positively associated with food-security impact after adjustment ($b = 0.590$). The estimated indirect association was 0.490 (bootstrap 95% CI 0.322-0.609), while the adjusted direct awareness-to-food-impact coefficient was 0.324. Because all variables were measured at one time from the same respondent, this decomposition does not establish temporal mediation. It quantifies covariance consistent with the proposed pathway and motivates longitudinal testing.

DISCUSSION

Surveyed farmers reported high levels of climatic, agricultural and food-system stress across three Liberian counties. The stability of scale means after removing 124 uniform response profiles is an important finding: broad endorsement persisted among respondents who differentiated their answers. This does not eliminate response bias, but it reduces the likelihood that the overall means were wholly created by straightlining.

The item profiles describe a compound-risk narrative. Reduced soil moisture, rising temperature, crop failure, delayed planting, pest and disease pressure, declining harvest, disrupted distribution, lower income and rising prices connect environmental stress with production and market access. This pattern is consistent with the IPCC's description of interacting climate and livelihood risks in Africa (IPCC, 2022, 2023). It also aligns with Liberia's policy emphasis on resilient production, climate information, land and water management, infrastructure and value chains (Republic of Liberia, 2021; Ministry of Agriculture, 2024).

County contrasts were large, but they are the most interpretation-sensitive result. Nimba and Lofa generally recorded higher perceived-impact scores than Bong. Yet the flagged response profiles were concentrated by county and enumerator, and enumerator assignment was not independent of geography. The observed differences may combine genuine exposure, livelihood context, questionnaire administration and response norms. County-sensitive programming is reasonable, but resource allocation should not rely on these coefficients alone.

The absence of unadjusted sex differences should also be interpreted cautiously. Similar means do not imply equal land rights, labour burdens, access to information, household decision-making or adaptive resources. A household survey respondent category is an incomplete measure of gendered vulnerability. Future research should measure control over land, income, technology and adaptation decisions and should combine quantitative analysis with qualitative accounts.

The adjusted models explained a meaningful but incomplete share of variance. Age, experience and household size may capture accumulated exposure, memory of past seasons, labour and consumption demands, but the grouped variables cannot identify mechanisms. The residual variance is likely to contain local hazard conditions, soil and crop differences, wealth, infrastructure, extension exposure, market access, social networks and measurement error.

The results have practical implications. First, climate services should address timing, soil moisture, heat and heavy-rainfall risks rather than only annual rainfall totals. Second,

extension packages should integrate crop calendars, pest surveillance, soil-water management and locally suitable varieties. Third, food-security planning should include roads, markets, price monitoring and income protection because respondents linked stress to distribution and purchasing power. Fourth, monitoring systems should pair farmer-reported indicators with station or gridded climate observations, crop cuts or production records and market data.

Strengths and Limitations

Strengths include a three-county sample, explicit construct definitions, item-level reporting, full and sensitivity samples, effect sizes and robust adjusted models. The analysis also maintains a clear boundary between perceptions and observed outcomes. Limitations include the cross-sectional design, same-source measurement, possible recall and social-desirability bias, uniform response patterns, county-enumerator confounding, grouped demographic covariates, absence of sampling weights and lack of verified climate, crop-output, income and nutrition records. Internal consistency does not establish construct validity, and a positively worded food-security item requires improved directional coding in future instruments.

CONCLUSIONS

Smallholder farmers in Bong, Lofa and Nimba Counties widely reported climatic exposure and adverse agricultural and food-system consequences. The aggregate pattern was robust to exclusion of uniform response profiles, while county contrasts remained substantial but potentially confounded by survey administration. The findings justify integrated climate-information, production, market and food-access interventions, but they do not quantify climate trends, yield loss or causal impact. A longitudinal, mixed-source design linking household panels with observed climate, crop, market and programme data is required for stronger attribution and policy targeting.

DECLARATIONS

Ethics approval and consent to participate: Ethical approval was granted by the Njala University Research Ethics Committee on 2 March 2025 (reference NURE_123NC). Participation was voluntary and based on informed consent.

Consent for publication: Not applicable; no identifiable participant information is reported.

Availability of data and materials: The de-identified analytical dataset and analysis code are not publicly deposited because release requires institutional authorisation and protection of participant confidentiality. Reasonable requests may be considered by the corresponding author, subject to approval by the Njala University Research Ethics Committee.

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Declaration: The authors reviewed and edited the content and take full responsibility for the manuscript.

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