

Article

Socio-Economic and Institutional Predictors of Climate Change Adaptation Among Smallholder Dairy Farmers in Plateau State, Nigeria

Hosea Istifanus Finangwai ¹, Peter Pano Barje ², Samuel Emmanuel Danbauchi ¹, Luka Yangka Guluwa ¹, Shedrach Benjamin Pewan ^{3,*} and Dashe Yakubu Gunya ³

¹ Department of Animal Science, Faculty of Agriculture, Plateau State University, Bokkos 932112, Nigeria; hoseaifinangwai@plasu.edu.ng (H.I.F.); danbauchiemmanuel@plasu.edu.ng (S.E.D.); guluwaluka@plasu.edu.ng (L.Y.G.)

² National Animal Production Research Institute, Ahmadu Bello University, Zaria 810105, Nigeria; ppbarje@napri.gov.ng

³ Extension Division, National Veterinary Research Institute, Vom 930001, Nigeria; yakubudashe@yahoo.co.uk

* Correspondence: shedrach.pewan@my.jcu.edu.au

Abstract

Climate change presents significant challenges for smallholder dairy farmers, especially in developing countries where production relies heavily on natural resources. This study examined factors linked to climate change adaptation among smallholder dairy farmers in Plateau State, Nigeria. A cross-sectional survey was conducted with 400 farmers selected through multistage sampling across eight major dairy-producing Local Government Areas. Data collection involved structured questionnaires, key informant interviews, and focus group discussions. Analysis included descriptive statistics, Pearson's chi-square test, one-way ANOVA, and multiple linear regression. The results showed that dairy farming is mostly practised by economically active male farmers. Many respondents noticed changes in rainfall and rising temperatures, but awareness of climate change and its impact on dairy production was generally low. Farmers identified seasonal feed shortages, declining forage quality, water scarcity, heat stress, and reduced feed intake as key challenges. While some adaptation measures, such as adjusting grazing practices and water management, had been adopted, many found them to be ineffective. Regression analysis indicated that education, climate change awareness, access to extension services, and feed availability significantly influenced adaptation outcomes, with the model explaining 61.0% of the variation ($R^2 = 0.610$). Access to extension services had the strongest impact. The results highlight the need to strengthen institutional support to boost smallholder farmers' adaptive capacity. Enhancing livestock extension programmes, raising awareness about climate change, improving access to information, and promoting climate-smart dairy management and sustainable feed practices can improve the resilience and sustainability of dairy systems in Plateau State and similar regions.

Keywords: climate resilience; livestock productivity; extension services; feed resources; climate-smart agriculture; adaptation strategies

Academic Editor: Joanna Sender

Received: 15 June 2026

Revised: 31 July 2026

Accepted: 31 July 2026

Published: 3 August 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

Climate change is among the biggest threats to global agricultural sustainability, affecting food security, rural lives, and economic growth. Agricultural productivity is highly vulnerable because it depends on climate factors such as temperature, rainfall, feed, water, and disease risk [1]. Recent studies show that rising temperatures, changing rainfall patterns, prolonged droughts, and extreme weather are already negatively impacting agriculture worldwide, where production systems are predominantly rain-fed and highly climate-sensitive [2,3]. Across sub-Saharan Africa, smallholder livestock farmers depend heavily on climate-sensitive natural resources, making dairy production especially susceptible to environmental variability [4]. Livestock systems are particularly vulnerable because animal health, performance, and welfare rely heavily on environmental conditions and access to feed and water. Consequently, enhancing the adaptive capacity of livestock farmers has become a major global priority for achieving resilient and sustainable food systems [4].

Smallholder dairy production is a cornerstone of rural economies in many developing regions, particularly across sub-Saharan Africa, where it contributes substantially to household earnings, food and nutrition security, and the livelihoods of farming communities. However, the sector faces growing challenges associated with climate variability and climate change [5]. Heat stress, seasonal feed shortages, declining pasture quality, water scarcity, and increased incidence of livestock diseases have become major constraints to sustainable dairy production [6,7]. These challenges are particularly severe among smallholder dairy farmers who often operate under resource-constrained conditions characterized by limited access to improved technologies, climate information, extension services, and financial resources [8,9].

Among livestock enterprises, dairy production is highly sensitive to climate variability and change. Elevated ambient temperatures and heat stress can reduce feed intake, impair reproductive efficiency, increase water requirements, and lower milk yield [10,11]. In addition, changes in rainfall patterns influence forage growth, pasture quality, and feed availability, thereby constraining dairy productivity and farm profitability. Recent studies have highlighted the growing vulnerability of dairy systems to climate-induced challenges, including heat stress, feed shortages, water scarcity, and increased disease risks [12,13], all of which threaten the sustainability of dairy farming globally and particularly within smallholder production systems. According to NiMet [14], climate change has manifested in rising ambient temperatures, erratic rainfall patterns, delayed onset and early cessation of rainfall, increased frequency of droughts, and occasional flooding. These climatic changes have significant implications for livestock production systems, particularly dairy farming. Studies have shown that elevated temperatures reduce feed intake, impair reproductive performance, increase water requirements, and lower milk yield in dairy cattle [15,16].

Plateau State occupies a unique position within Nigeria's dairy industry due to its relatively cool climate, high-altitude environment, and favourable agroecological conditions that support dairy cattle production. Historically, the state has served as an important hub for dairy farming, particularly for indigenous breeds such as Bunaji and improved dairy breeds, including Friesian crosses. However, recent climatic shifts have begun to undermine this comparative advantage. Farmers increasingly report challenges associated with prolonged dry seasons, irregular rainfall distribution, heat stress, declining pasture quality, and seasonal water shortages, all of which negatively affect dairy productivity and profitability. These emerging challenges threaten the sustainability of dairy enterprises and the livelihoods of smallholder farmers who depend on them.

Adaptation has therefore become an essential strategy for enhancing resilience within dairy production systems. Climate change adaptation refers to adjustments in management practices, technologies, and institutional arrangements aimed at reducing

vulnerability and improving farmers' capacity to cope with climatic stresses [17]. In dairy production, adaptation measures may include improved feeding strategies, forage conservation, climate-resilient pasture development, water resource management, improved housing systems, strategic grazing management, breed improvement, and the use of climate information services [18,19]. The success of these adaptation measures, however, depends on several socio-economic, institutional, and farm-level factors.

Previous empirical studies have demonstrated that farmers' educational attainment, awareness of climate change, access to extension services, and availability of production resources significantly influence adaptation behaviour and outcomes [20–22]. Education enhances farmers' ability to acquire, interpret, and apply technical information, thereby facilitating informed decision-making. Climate awareness improves risk perception and encourages proactive adaptation responses [23]. Extension services serve as critical channels for disseminating innovations, technical knowledge, and climate-smart agricultural practices. Likewise, adequate feed availability is fundamental for sustaining livestock productivity and improving resilience under changing climatic conditions [24].

Although awareness of the importance of climate change adaptation in livestock farming is growing, empirical data on the factors influencing adaptation among smallholder dairy farmers in Nigeria remain limited, particularly in Plateau State, a key dairy-producing area. Past research has largely focused on climate change impacts on agriculture and farmers' perceptions, with less attention to the socio-economic, institutional, and production-related factors that affect the success of adaptation. Filling this gap is crucial for creating effective strategies that enhance farmers' adaptive capacity and encourage climate-smart dairy practices. The main goal of the study was to identify the factors influencing climate change adaptation among smallholder dairy farmers in Plateau State, Nigeria. The research used multiple linear regression to examine whether variables such as educational level, awareness of climate change, access to extension services, and feed availability were significantly associated with adaptation outcomes. The null hypothesis (H_0) stated that no significant relationship existed, while the alternative hypothesis (H_1) stated that at least one factor was significantly related. The results offer valuable insights to inform policies, extension programs, and climate-smart dairy initiatives aimed at enhancing the resilience and sustainability of smallholder dairy farmers.

2. Materials and Methods

2.1. Study Area

The study was conducted in Plateau State, North-Central Nigeria, located between latitude 8°24' N and 10°38' N and longitude 8°32' E and 10°38' E. Plateau State occupies approximately 30,913 km² and is characterized by a unique highland ecology with elevations ranging from 1200 to over 1800 m above sea level. The state experiences a relatively moderate climate compared with most parts of Nigeria, with mean annual temperatures ranging from 18 °C to 27 °C and annual rainfall between 1200 and 1500 mm. The distinct wet (April–October) and dry (November–March) seasons provide favourable conditions for livestock production, particularly dairy cattle.

2.2. Study Population

The target population comprised smallholder dairy farmers actively engaged in dairy production within the selected LGAs of Plateau State. For this study, a smallholder dairy farmer was defined as an individual or household that owns and manages dairy cattle primarily for milk production and operates under traditional, semi-intensive, or intensive systems. To be included in the study, respondents had to own at least one lactating dairy cow at the time of the survey, have been involved in dairy farming for at least one

year, live within the selected study area, and provide informed consent to participate. The estimated population of Plateau State was projected at 4,717,300 based on the 2006 National Population Census and subsequent projections by NBS [25]. Although the study targeted dairy farmers rather than the general population, this projection was used in determining an adequate sample size for a large finite population.

2.3. Research Design

A cross-sectional survey was used to collect data from respondents at a single point in time. This approach was suitable because it enabled the simultaneous evaluation of farmers' perceptions, adaptation strategies, and climate experiences across various locations. Additionally, it enables analysis of the relationships between adaptation outcomes and specific socio-economic, institutional, and farm-related variables.

A cross-sectional survey research design was adopted for this study. The design was considered appropriate because it permits the collection of quantitative and qualitative data from a representative sample of respondents at a single point in time while enabling the examination of relationships among socio-economic characteristics, institutional factors, climate-related variables, and adaptation outcomes. The design also facilitated the application of inferential statistical techniques to identify significant predictors of climate change adaptation among smallholder dairy farmers.

The study was guided by the conceptual framework developed from the Sustainable Livelihood Framework [26] and the Climate Change Adaptation Framework [3], which informed the selection of explanatory variables, questionnaire development, and statistical modelling.

2.4. Sample Size Determination

The study's sample size was calculated using Yamane's formula [27] for finite populations. Based on the projected population of Plateau State, estimated at 4,717,300 residents by the National Population Commission and the National Bureau of Statistics, the required sample size was determined as follows:

$$n = \frac{N}{1 + N(e)^2}$$

where

- n = required sample size;
- N = population size (4,717,300);
- e = level of precision (0.05).

A minimum sample size of 400 smallholder dairy farmers was considered adequate for the study, based on recommendations for multiple linear regression analysis and Yamane's formula (5% margin of error), ensuring sufficient statistical power to detect associations among the study variables and adequately represent the target population.

2.5. Sampling Procedure

A multistage sampling method was used to select respondents. Initially, eight dairy-producing LGAs (Bokkos, Jos East, Jos North, Jos South, Kanam, Mangu, Shendam and Wase) as shown in Figure 1 were purposively selected based on dairy cattle population, accessibility and ecological representation. Stage two: Key dairy communities within each LGA were identified through consultations with agricultural extension workers, community leaders, and livestock associations. Thirdly, eligible dairy farmers were identified, and respondents were selected using proportionate simple random sampling to ensure adequate representation across the study locations. Ultimately, 400 smallholder dairy farmers were interviewed, averaging about fifty per LGA.

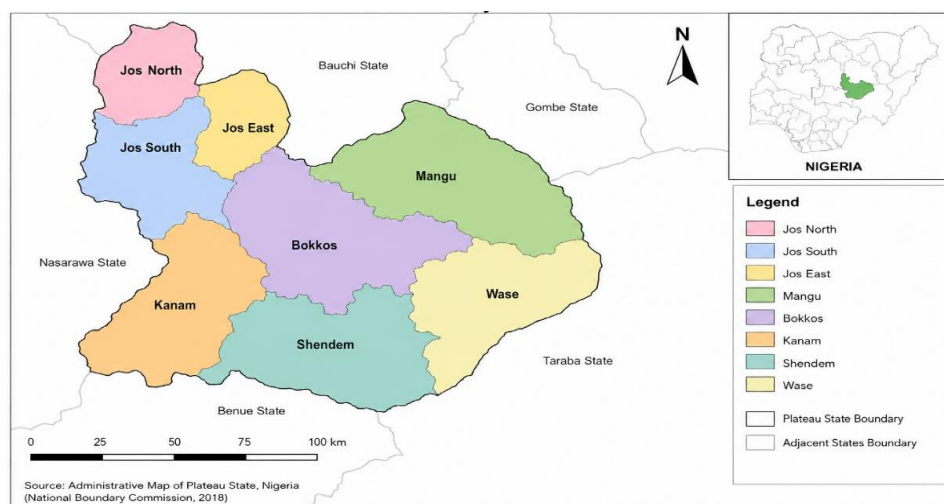


Figure 1. Map of Plateau State showing the 8 Local Government Areas included in the study.

2.6. Inclusion and Exclusion Criteria

To ensure the quality and relevance of data collected, respondents were selected based on the following inclusion criteria: ownership of at least one lactating dairy cow, active involvement in dairy farming for at least two years before the survey, residence within the study area throughout the study period, and willingness to participate voluntarily after providing informed consent. Farmers who did not own dairy cattle, were temporary residents, or declined participation were excluded from the study.

2.7. Data Collection Methods

Data collection was undertaken using a mixed-methods approach that combined quantitative and qualitative methods to enhance data reliability and validity.

2.7.1. Structured Questionnaire Survey

Primary data were collected through structured face-to-face interviews using a pre-tested questionnaire. The survey instrument was designed to capture respondents' demographic and socio-economic characteristics, awareness and perceptions of climate change, observed climatic variations, feed and water resource availability, milk production trends, animal health constraints, farm management practices, adaptation and coping mechanisms, access to extension and climate information services, and farmers' assessments of the effectiveness of existing adaptation measures. The questionnaire comprised predominantly closed-ended questions, complemented by a limited number of open-ended items to elicit additional perspectives and contextual information from participants. The questionnaire included both closed-ended and Likert-scale questions.

2.7.2. Key Informant Interviews (KIIs)

Key informant interviews were conducted with individuals who have in-depth knowledge of dairy production and climate issues in the study area. Participants included livestock extension officers, veterinarians, dairy cooperative leaders, community leaders, seasoned dairy farmers and officials of the Plateau State Ministry of Agriculture. These interviews provided contextual information regarding climate variability, extension services, institutional support and adaptation programmes.

2.7.3. Focus Group Discussions (FGDs)

FGDs were held in selected communities to encourage collective reflection on climate variability and adaptation experiences. These discussions enabled participants to share their experiences of weather changes, livestock management, feed availability, and adaptation strategies. The insights gained from the FGDs complemented and validated the results of the questionnaire survey, providing deeper insights into climate-related production challenges and local adaptation strategies.

2.7.4. Validity and Reliability of Research Instrument

The questionnaire was administered through face-to-face interviews conducted in English, Hausa, and local dialects where necessary. Its content validity was assessed by experts in Animal Science, Agricultural Extension, Climate Change, and Research Methodology at Plateau State University, Boko. A pilot survey of 30 dairy farmers outside the selected study communities was conducted to assess the instrument's clarity, consistency, and suitability. Completed questionnaires were checked for completeness, consistency, and accuracy before data entry.

2.8. Enumerator Recruitment and Training

Sixteen enumerators were recruited and trained for the field survey, with two assigned to each selected LGA. The training covered the study objectives, ethical considerations, questionnaire administration, interview techniques, and quality control. Before the main survey, a pilot test of the questionnaire was conducted to identify and resolve ambiguities and to enhance instrument reliability.

2.9. Variables Measured

2.9.1. Dependent Variable

The dependent variable in the regression analysis was the Dairy Adaptation Outcome. It was measured using composite indicators based on respondents' adaptation practices, their perceptions of the effectiveness of these measures, and their resilience to climate-related challenges.

2.9.2. Independent Variables

The explanatory variables in the analysis included respondents' educational attainment, access to climate information, level of climate-change awareness, access to extension services, feed and water availability, gender, age, farming experience, breed type, and farm management practices. Additionally, relevant socio-economic characteristics related to dairy production and adaptation capacity were considered to evaluate their impact on farmers' adaptation outcomes.

2.10. Data Analysis

Quantitative data were coded, entered, cleaned, and analyzed using IBM SPSS Statistics version 29 [28]. Descriptive statistics such as frequencies, percentages, means, and standard deviations summarized the data generated from respondents' socio-economic characteristics and adaptation practices. Inferential analyses, including Pearson's chi-square test, independent samples *t*-test, one-way ANOVA, and multiple linear regression, were used to explore relationships among variables and identify key predictors of dairy adaptation outcomes. Pearson's Chi-square test examined associations between categorical variables, including climate awareness and perceived climate impacts, access to climate information and adaptation effectiveness. An independent samples *t*-test assessed gender differences in climate awareness. One-way Analysis of Variance (ANOVA) was

used to evaluate differences in climate awareness across educational levels. Multiple Linear Regression Analysis identified the socio-economic and institutional predictors of climate change adaptation among smallholder dairy farmers. The composite Dairy Adaptation Outcome Index (DAOI) was used as the dependent variable in a multiple regression analysis, with education, climate awareness, extension access, and feed availability as independent variables. A multiple linear regression model was specified as:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \varepsilon$$

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \varepsilon$$

where

- Y = Dairy Adaptation Outcome;
- X_1 = Educational Level;
- X_2 = Climate Change Awareness;
- X_3 = Extension Access;
- X_4 = Feed Availability;
- β_0 = Intercept;
- $\beta_1 - \beta_4$ = Regression coefficients; and
- ε = Random error term.

Statistical significance was evaluated at the 5% probability level ($p < 0.05$).

Qualitative data collected from Key Informant Interviews and Focus Group Discussions were analysed through thematic content analysis. Responses were transcribed, coded, and organised into emerging themes, including climate variability, challenges in dairy production, adaptation strategies, and institutional support. These insights complemented the quantitative results, offering a more complete view of farmers' adaptation experiences.

3. Results

3.1. Demographic Characteristics of Respondents

The socio-demographic profile of respondents is presented in Table 1. The 400 dairy farmers surveyed were reasonably distributed across the eight selected Local Government Areas (LGAs), ensuring adequate geographical representation of the major dairy-producing zones in Plateau State. Jos North accounted for the largest share of respondents (15.3%), while Wase recorded the smallest share (9.5%). This distribution reflects the relative concentration of dairy farming activities across study locations.

Table 1. Demographic Characteristics of Respondents (N = 400).

Variable	Category	Frequency (f)	Percentage (%)
Local Government Area	Jos North	61	15.3
	Jos East	57	14.2
	Bokkos	47	11.8
	Kanam	52	13.0
	Mangu	40	10.0
	Jos South	55	13.8
	Wase	38	9.5
	Shendam	50	12.5
	Total	400	100.0
Gender	Male	252	63.0
	Female	148	37.0
	Total	400	100.0
Age Category (Years)	<25	38	9.5
	25–34	56	14.0

	35–44	90	22.5
	45–54	107	26.8
	55–64	71	17.8
	≥65	38	9.5
	Total	400	100.0
Educational Level	No formal education	88	22.0
	Primary education	102	25.5
	Secondary education	83	20.8
	Tertiary education	63	15.8
	Adult literacy	64	16.0
	Total	400	100.0
Primary Occupation	Dairy farming	57	14.3
	Mixed farming	134	33.5
	Crop + livestock farming	174	43.5
	Civil service + dairy	9	2.3
	Others	26	6.5
	Total	400	100.0
Breed of Animals	Bunaji	300	75.0
	Friesian × Bunaji and other crosses	85	21.3
	Holstein Friesian cattle	15	3.8
	Total	400	100.0

The gender composition showed that dairy production was predominantly male-driven, with males accounting for 63.0% of respondents and females 37.0%. This finding suggests that ownership and management of dairy enterprises in the study area remain largely under male control, although women continue to play important supportive roles within household dairy systems.

The age structure of respondents indicated that dairy farming was largely practised by economically active adults. Farmers aged 45–54 years made up the largest share (26.8%), followed by those aged 35–44 years (22.5%). By contrast, farmers under 25 accounted for only 9.5% of the sample. The predominance of middle-aged farmers suggests that dairy production in the study area is sustained by individuals with considerable farming experience and accumulated knowledge, while youth participation remains relatively low.

Educational attainment among respondents was generally modest. Primary education was the most common category (25.5%), followed by respondents with no formal education (22.0%). Secondary education accounted for 20.8%, while tertiary education represented only 15.8% of respondents. The relatively low level of formal education may affect farmers' access to technical information and climate advisories, as well as their adoption of improved dairy management practices.

Regarding occupation, mixed crop-livestock production dominated the farming systems. Crop and livestock farming was the primary occupation for 43.5% of respondents, while 33.5% practised mixed farming. Only 14.3% engaged exclusively in dairy farming. This finding highlights the importance of livelihood diversification as a risk-management strategy among rural households.

Considering breed composition, indigenous Bunaji cattle were the dominant dairy breed, accounting for 75.0% of the animals kept by respondents. Crossbred cattle represented 21.3%, while pure Holstein Friesian cattle accounted for only 3.8%. The predominance of indigenous breeds reflects their superior adaptability to local environmental conditions, disease resistance, and lower management requirements compared with exotic breeds.

Overall, the demographic characteristics indicate that dairy farming in Plateau State is largely managed by middle-aged male farmers who operate mixed farming systems with indigenous cattle breeds and have relatively low levels of formal education.

3.2. On-Farm Management Practices and Adaptation Measures

Management practices and adaptation measures adopted by participating dairy farmers are summarised in Table 2. The findings indicate that dairy production in the study area remains predominantly traditional. A substantial majority of respondents (80.3%) practised extensive grazing systems, while only 19.7% utilized alternative production systems. This heavy dependence on open grazing exposes dairy herds to climatic risks, including forage scarcity, heat stress, farmer–herder conflicts, ingestion of toxic plants, and fluctuating pasture availability, all of which adversely affect animal health, welfare, and milk production.

Table 2. Farm Management and Adaptation Strategies (N = 400).

Variable	Category	Frequency (f)	Percentage (%)
Grazing system	Extensive system	321	80.3
	Other systems	79	19.7
	Total	400	100.0
Housing type	Sheds/roofed	311	77.8
	Other housing types	89	22.2
	Total	400	100.0
Feed storage/feed reserve source	Crop residues	325	81.3
	Other feed sources	75	18.7
	Total	400	100.0
Adaptation strategy	Changing water sources	244	61.0
	Early/Late grazing	156	39.0
	Total	400	100.0
Effectiveness of strategies	Not effective/uncertain	367	91.8
	Effective	33	8.2
	Total	400	100.0

Despite the prevalence of extensive grazing, 77.8% of respondents reported housing their animals in sheds or other roofed structures. This suggests a growing awareness of the importance of shelter in protecting livestock from adverse weather and improving animal welfare.

Feed reserve practices were largely based on crop residues, with 81.3% of respondents using them as supplementary feed. This dependence reflects limited adoption of improved forage conservation technologies, such as haymaking and silage production. Given their relatively low nutritional value, reliance on crop residues may constrain animal productivity, particularly during prolonged dry seasons when natural forage resources become scarce.

Farmers reported a range of adaptation measures to cope with climatic challenges. The most common strategy was changing water sources (61.0%), followed by early or late grazing (39.0%). These measures are practical responses to water scarcity and heat stress. However, despite their widespread adoption, the perceived effectiveness of these strategies was remarkably low. More than nine out of every ten respondents (91.8%) considered the adaptation measures ineffective or were uncertain about their effectiveness.

This finding highlights a significant adaptation gap, indicating that current coping mechanisms are insufficient to address the growing impacts of climate variability on dairy production. Consequently, there is an urgent need for climate-smart interventions to enhance adaptive capacity and strengthen the resilience of smallholder dairy systems.

3.3. Milk Handling Practices, Extension Services and Socioeconomic Impacts

Table 3 summarizes milk handling practices, access to climate-related information, and the socioeconomic implications of climate variability among dairy farmers.

Table 3. Milk Handling, Extension Services, and Socioeconomic Impacts.

Variables	Category	Frequency	Percentage (%)
Milk handling	Stainless steel containers	238	58.5
Cooling practice	No	257	64.3
Climate information access	No	265	66.3
Source of information	Radio	247	61.8
Income impact	No change	268	67.0
Feed cost trend	Slightly higher	199	49.8

Regarding milk hygiene practices, 58.5% of respondents reported using stainless-steel containers for milk handling. This is a positive step towards improved milk quality and safety, as stainless-steel containers reduce the risk of contamination and facilitate cleaning. Nevertheless, the remaining proportion of farmers continue to use alternative containers that may compromise milk quality.

Milk preservation practices were generally inadequate. Approximately 64.3% of respondents reported not cooling milk before sale. This finding raises concerns about post-harvest milk losses, particularly as environmental temperatures rise. The absence of cooling facilities leads to rapid spoilage of milk, reducing product quality and market value.

Access to climate information was also limited. About two-thirds (66.3%) of respondents reported having no access to climate-related information. This deficiency significantly constrains farmers' ability to anticipate weather-related risks and make informed management decisions. Among farmers who accessed information, radio emerged as the dominant communication channel (61.8%), highlighting its continued importance as a medium for agricultural extension and climate advisory services in rural communities.

The socioeconomic implications of climate variability were evident in household income and production costs. Although 67.0% of respondents reported no significant change in income, nearly half (49.8%) observed rising feed costs compared with previous years. Rising feed costs may be linked to declining forage availability, seasonal feed shortages, and greater reliance on purchased feed. Such increases can reduce farm profitability and threaten the sustainability of dairy enterprises.

Overall, the findings indicate that inadequate milk-preservation infrastructure, limited access to climate information, and rising feed costs remain major constraints on sustainable dairy production in the study area.

3.4. Major Climate-Related Challenges and Recommended Adaptation Measures

The major climate-related challenges affecting dairy production and farmers' recommended adaptation measures are presented in Table 4.

Table 4. Key Challenges and Recommendations.

Variables	Category	Frequency	Percentage (%)
Major climate challenge	Heat stress	202	50.5
Major climate challenge	Rainfall variability	198	49.5
Recommended solutions	Heat stress management	277	69.3
Recommended solutions	Climate-resilient forage	123	30.8

Heat stress was the most frequently reported challenge, cited by 50.5% of respondents. Rainfall variability was close second, reported by 49.5% of respondents. The near-equal prevalence of these challenges suggests that both rising temperatures and unpredictable rainfall patterns are exerting considerable pressure on dairy production systems.

Heat stress affects dairy cattle directly by reducing feed intake, milk production, reproductive efficiency, and overall physiological performance. Rainfall variability influences dairy production indirectly by affecting pasture growth, forage quality, and water availability.

In response to these challenges, most respondents (69.3%) identified improved heat-stress management as the most important adaptation measure. Suggested interventions included providing shade, improving housing structures, increasing water availability, and adjusting grazing schedules. Additionally, 30.8% recommended promoting climate-resilient forage species that maintain productivity under drought and variable climatic conditions.

These findings demonstrate that farmers clearly recognize the importance of addressing both thermal stress and feed resource constraints as critical components of climate adaptation in dairy production systems.

3.5. Multiple Linear Regression Analysis of Predictors of Dairy Adaptation Outcomes

3.5.1. Model Summary

The model summary in Table 5 indicates that the regression model fits the data well. The multiple correlation coefficient ($R = 0.781$) shows a strong positive association between the explanatory variables and dairy adaptation outcomes.

Table 5. Model Summary for Multiple Linear Regression Analysis.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.781	0.610	0.604	0.587

Predictors: (Constant), Education, Climate Awareness, Extension Access, Feed Availability.

The coefficient of determination ($R^2 = 0.610$) indicates that approximately 61.0% of the variation in adaptation outcomes was explained by the combined effects of education, climate awareness, extension access, and feed availability. The adjusted R^2 of 0.604 suggests that the model retained substantial explanatory power after accounting for the number of predictors.

The standard error of the estimate (0.587) further indicates that the model has satisfactory predictive accuracy. Collectively, these statistics demonstrate that the selected variables are important determinants of dairy adaptation outcomes among the participating smallholder farmers in Plateau State.

3.5.2. Analysis of Variance (ANOVA)

The overall significance of the regression model is presented in Table 6. The model yielded an F-statistic of 154.893 with a p -value of $p < 0.001$, indicating that the regression equation was highly significant.

Table 6. ANOVA for Multiple Linear Regression Model.

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	213.582	4	53.396	154.893	0.000
Residual	136.418	395	0.345	-	-
Total	350.000	399	-	-	-

The significant F-test confirms that the predictor variables jointly explain variation in dairy adaptation outcomes. Consequently, the null hypothesis that explanatory variables have no significant effect on adaptation outcomes is rejected.

These results validate the regression model's suitability for assessing determinants of adaptation performance among smallholder dairy farmers.

3.5.3. Regression Coefficients of Predictors

The regression coefficients are presented in Table 7. The findings indicate that all four explanatory variables significantly affected dairy adaptation outcomes.

Table 7. Regression Coefficients for Predictors of Dairy Adaptation Outcomes.

Model	Unstandardized B	Std. Error	Standardized Beta	t	Sig.
(Constant)	0.842	0.198	-	4.253	0.000
Education	0.276	0.061	0.254	4.525	0.000
Climate Awareness	0.391	0.072	0.336	5.431	0.000
Extension Access	0.488	0.058	0.472	8.414	0.000
Feed Availability	−0.167	0.052	−0.148	−3.212	0.001

Access to extension services emerged as the strongest predictor of adaptation success ($\beta = 0.472$, $p < 0.001$). This suggests that farmers with greater access to extension services are significantly more likely to adopt effective adaptation measures and achieve better adaptation outcomes. Extension services provide critical technical knowledge, advisory support, and access to innovations that enhance adaptive capacity.

Climate awareness was the second most influential predictor ($\beta = 0.336$, $p < 0.001$). Farmers with greater awareness of climate-related risks achieved stronger adaptation outcomes, underscoring the importance of raising awareness and disseminating climate information to build resilience.

Education also had a significant positive effect on adaptation outcomes ($\beta = 0.254$, $p < 0.001$). The positive coefficient indicates that higher educational attainment enhances farmers' ability to understand, evaluate, and implement climate-smart management practices.

In contrast, feed availability showed a significant negative association with adaptation outcomes ($\beta = -0.148$, $p = 0.001$). This result indicates that reduced feed availability undermines the effectiveness of adaptation and limits farmers' capacity to cope with climate-related challenges. Feed shortages, therefore, remain a major constraint on sustainable dairy production.

Taken together, the regression results identify extension access, climate awareness, education, and feed availability as critical determinants of adaptation success. Among these factors, access to extension services had the greatest influence, emphasising the strategic importance of strengthening agricultural extension systems and advisory climate services to enhance resilience among smallholder dairy farmers in Plateau State.

3.5.4. Farmers' Awareness and Perception of Climate Change

Respondents generally exhibited limited formal awareness of climate change. Only 20.0% reported being aware of climate change as a scientific phenomenon, whereas 80.0% indicated no formal awareness (Table 8). Despite this low level of awareness, 74.0% acknowledged that changing climatic conditions negatively affected dairy production. The most frequently observed climatic change was increasing temperature (79.8%), followed by irregular rainfall (20.2%).

Table 8. Climate change awareness and perception among respondents.

Variable	Category	Frequency (f)	Percentage (%)
Awareness of climate change	Yes	81	20.0
	No	319	80.0
	Total	400	100.0
Observed changes in climate	Increased heat	319	79.8
	Irregular rainfall	81	20.2
	Total	400	100.0
Perceived effect on dairy farming	Yes	296	74.0
	No	100	25.0
	Not sure	4	1.0
	Total	400	100.0

4. Discussion

This study from the sampled farms offers valuable insights into the factors influencing dairy adaptation among smallholder farmers in Plateau State, Nigeria. The findings show that climate variability is increasingly affecting dairy production systems, and farmers' ability to adapt is heavily influenced by socio-economic, institutional, and production-related factors. The discussion aligns with the study's main objectives.

4.1. Socio-Demographic Characteristics and Dairy Farming

The study revealed that most dairy farmers in Plateau State are men, constituting 63.0% of respondents. This reflects Nigeria's traditional livestock system, where men predominantly own and oversee cattle, while women typically handle tasks such as milk processing and marketing [29,30]. The predominance of male farmers suggests that climate adaptation strategies for dairy farming should consider household decision-making processes to ensure effective adoption and implementation.

Most respondents fall within the economically active age group of 35–54 years, suggesting that dairy farming is predominantly operated by mature individuals with substantial experience. This age range may boost adaptive capacity, as experienced farmers are more adept at detecting environmental shifts and applying knowledge-based management strategies. Similar findings have been documented in studies of livestock farmers across sub-Saharan Africa, where farming experience plays a key role in adaptive decision-making under climate stress [31,32].

Respondents generally had low levels of education, with many having only primary schooling or none. This lack of educational background could limit farmers' capacity to access, comprehend, and apply climate-related data and modern dairy practices. Education is widely recognized as a key factor in adopting new technologies and adapting to climate challenges in agriculture [33–35]. Therefore, the observed low educational levels underscore the need to implement simplified extension methods and farmer-focused training initiatives.

4.2. Climate Change Awareness and Perception

One of the study's most notable findings is the low awareness of climate change among respondents, despite many observing climatic shifts. While many farmers reported irregular rainfall and higher temperatures, few recognised climate change as a broader environmental issue. This disconnect between personal experience and scientific understanding has also been observed in developing and even developed countries, where farmers often notice environmental changes but do not fully grasp their causes [36,37].

Irregular rainfall was the most common climatic change observed, underscoring the increasing unpredictability of weather patterns in Plateau State. Variations in rainfall directly impact forage production, water supply, and livestock productivity. This aligns with reports from the Nigerian Meteorological Agency [14], which documents rising rainfall uncertainty across many regions in Nigeria. The respondents' low awareness of climate change as a threat to dairy production may partly explain the limited success of adaptation efforts, as risk perception plays a crucial role in driving adaptive actions.

4.3. Feed Availability, Milk Production, and Animal Health

Feed availability is a critical determinant of dairy productivity because adequate, balanced nutrition promotes animal health, reproduction, milk production, and overall performance, helping to meet the increasing demand for high-quality dairy products [38,39]. In this study, although most respondents reported consistent year-round feed availability, heavy reliance on crop residues as the primary feed source raises concerns about their quality and nutritional value. Crop residues are often low in protein and difficult to digest, making them insufficient on their own to achieve optimal milk production. This reliance shows that apparent feed availability does not necessarily mean the feed is nutritionally adequate. To address the limitations of using crop residues as dairy feed, farmers should implement integrated feeding strategies that blend crop residues with protein-rich forage legumes, concentrate supplements, and feed-enhancement technologies such as urea treatment and ensiling [40,41]. These approaches can enhance the nutritional quality and digestibility of available feeds, leading to higher milk production and improved dairy productivity, especially during times of feed shortage.

The study also showed a clear seasonal fluctuation in milk yield, with significantly higher production during the rainy season compared to the dry season. This pattern is mainly due to seasonal forage availability and environmental factors affecting dairy performance. In the rainy season, better pasture growth increases both the quantity and quality of feed, leading to higher milk output. Conversely, the dry season typically involves forage shortages, heat stress, and reduced feed intake, resulting in lower milk yields. Similar results were documented by Thornton et al. [6], who highlighted that seasonal feed shortages are a major factor behind reduced dairy productivity in tropical systems.

Respondents identified several health issues, particularly decreased appetite and heat stress in their animals. Heat stress causes significant changes in animal behaviour, physiology, and metabolism, resulting in reduced feed intake, increased water requirements, faster breathing, and hormonal imbalances [42,43]. It can also increase methane intensity, decrease rumen motility, alter ruminal microbiota, modify fermentation processes, and sometimes increase ruminal pH and temperature, all of which can affect digestive efficiency and nutrient utilisation [44,45]. Reduced feeding, a typical response to heat, helps animals lower their metabolic heat production [46,47]. Persistent heat stress can negatively impact milk production, reproductive health, immune function, and overall animal well-being. The prevalence of these health problems indicates that climate change is affecting dairy cattle in the area through both direct and indirect effects.

4.4. Farm Management Practices and Adaptation Strategies

This study shows that many farmers are slowly shifting from extensive traditional methods to more managed, semi-intensive systems. The widespread use of roofed sheds indicates growing awareness of the need to protect livestock from harsh environmental conditions. These investments are likely to enhance animal comfort and help minimise the impact of climatic stressors.

Farmers adopted several adaptation strategies to address climate-related issues, primarily by changing water sources and adjusting grazing schedules. These practical,

locally suitable measures aim to lessen livestock's exposure to water shortages and heat stress. However, the fact that many respondents found these strategies ineffective or were unsure of their effectiveness suggests that current adaptation efforts might not be sufficient to address the severity of present climatic challenges.

The limited success of adaptation measures may stem from gaps in technical knowledge, a lack of institutional backing, and resource shortages. This finding aligns with earlier research indicating that adaptation efforts often fall short when they lack sufficient information, funding, or extension support [48]. Therefore, there is a need for more holistic, climate-smart dairy strategies that integrate technological advances with robust institutional support.

4.5. Milk Handling Practices, Extension Services, and Socioeconomic Implications

Milk handling practices greatly influence product quality, food safety, and profitability [49,50]. The widespread use of stainless-steel containers among respondents marks a positive step in dairy hygiene practices. Stainless steel is less likely to become contaminated and is easier to clean, which helps lower microbial risks.

Although there has been progress, most respondents still do not cool milk before selling it, which makes the product prone to rapid spoilage in hot conditions. This reveals major infrastructure gaps in the dairy supply chain and emphasizes the importance of investing in rural milk collection and cooling facilities.

Most respondents had limited access to climate information and extension services. These services are vital for transferring technologies, enhancing adaptive capacity, and encouraging climate-smart farming methods. The restricted access observed in this study may partly account for low awareness and the perception that adaptation strategies are ineffective. Similar issues have been documented across Africa, where insufficient extension coverage is a key barrier to climate adaptation for smallholder farmers [51,52].

The socioeconomic impacts of climate variability were evident in rising feed costs and concerns about farm profitability. Rising feed prices are likely linked to declining forage availability, increased competition for feed resources, and higher costs for purchased feed inputs. These increases reduce profit margins and may discourage investment in improved dairy production technologies.

4.6. Predictors of Dairy Adaptation Outcomes

The study's primary contribution is the Multiple Linear Regression Analysis, which identifies the main factors behind dairy adaptation outcomes among smallholder farmers. The model accounts for 61.0% of the variation in these outcomes, demonstrating significant explanatory power and emphasising the relevance of the chosen predictor variables.

Access to extension services emerged as the most significant predictor of adaptation success. Access to extension services is frequently identified as a vital factor in successful climate change adaptation among agricultural households [53,54]. These services offer farmers essential, timely information on climate risks, adaptation strategies, and better management practices, helping them make well-informed decisions. Farmers who maintain regular contact with extension agents are more likely to adopt climate-smart technologies, diversify their production methods, improve resource efficiency, and implement strategies to mitigate risks [55]. By promoting knowledge exchange and supporting access to innovations, extension services are central to enhancing adaptive capacity and lowering vulnerability to climate-related shocks.

In this study, climate awareness is ranked as the second most influential predictor. Climate awareness enables individuals to understand the causes, effects, and risks of climate change. Having a solid grasp of climate-related risks is crucial for farmers, policymakers, and communities to identify potential threats, make informed decisions, and implement

appropriate adaptation and mitigation measures. Increased awareness enhances the ability to anticipate and address climate challenges, including droughts, floods, heat stress, and reduced agricultural yields [56]. Additionally, climate knowledge encourages proactive behaviours and the adoption of climate-smart technologies, enhancing adaptive capacity at the household and community levels. Research indicates that greater climate risk awareness correlates with better preparedness and more effective adaptation strategies [57,58].

Educational attainment significantly boosts adaptation outcomes. Farmers with more education are typically better at accessing information, assessing various adaptation strategies, and implementing advanced technologies. This finding supports earlier research highlighting education as a crucial factor in fostering agricultural innovation and enhancing adaptive capacity [59,60].

Feed availability significantly impacts adaptation outcomes. Climate change frequently hampers forage growth through drought, erratic rainfall, and land degradation, leading to seasonal feed shortages and reduced feed quality [61]. Farmers who have reliable access to ample, nutritious feed can maintain livestock productivity, minimise deaths, and uphold household income during adverse weather conditions. Consequently, feed availability enhances adaptive capacity by increasing the resilience of livestock systems to climate shocks and reducing environmental vulnerability [62,63]. Many studies emphasise that feed security is vital for climate-resilient livestock production, especially among smallholder farmers in developing countries [64,65]. Having sufficient feed resources enables farmers to maintain milk production and animal health during periods of climate stress. In contrast, feed shortages decrease productivity and hinder the success of adaptation strategies.

Overall, the findings indicate that adaptation success among smallholder dairy farmers depends not just on climatic factors but also significantly on access to information, education, institutional support, and production resources. Improving these aspects will be vital for increasing resilience and supporting sustainable dairy farming amid changing climate conditions.

4.7. Farmers' Awareness and Perception of Climate Change

Although only about one-fifth of respondents reported formal awareness of climate change, nearly three-quarters acknowledged that changing climatic conditions negatively affect dairy production. This apparent contradiction, as also reported by Karki and his colleagues [66], indicates that farmers clearly experience climate variability but often lack the scientific terminology needed to describe it.

Most respondents identified increasing temperature and irregular rainfall as the principal climatic changes affecting dairy production. These observations are consistent with recent meteorological evidence showing increasing temperatures and rainfall variability across Nigeria [3,14]. Heat stress has been widely recognized as one of the greatest constraints to dairy productivity because elevated temperatures reduce feed intake, impair reproductive performance, suppress immune function, and decrease milk production.

The highly significant Chi-square relationship between climate awareness and perceived climate impacts confirms that awareness strongly influences farmers' understanding of climate-related production risks. Farmers who possess better climate knowledge are more likely to recognise environmental changes and implement appropriate adaptation strategies [67–69]. Similar findings have been reported in several African and Asian studies, where climate literacy significantly improved farmers' adaptive decision-making [70–72]. The implication is that increasing climate awareness through extension education, farmer field schools, radio programmes, and digital advisory services could substantially improve adaptation among smallholder dairy farmers.

4.8. Implications for Policy and Practice

The study emphasises the importance of implementing integrated, climate-smart strategies for dairy development in Plateau State and similar agroecological regions. Policymakers should focus on enhancing agricultural extension services, improving the communication of climate information, boosting farmer education and capacity building, and supporting efforts to develop feed resources. Additionally, investing in forage conservation technologies, climate-resistant pasture species, water infrastructure, and rural milk-cooling facilities will improve dairy farmers' ability to adapt to changing conditions. These interventions will boost resilience to climate change, increase milk output, raise household incomes, enhance food security, and promote the sustainable growth of Nigeria's dairy industry.

4.9. Study Limitations

This study faces several limitations. A cross-sectional design restricts the ability to infer causality and does not account for changes over time in adaptation practices. Since data largely rely on farmers' self-reported responses, they are susceptible to recall and social desirability biases. The purposive selection of dairy-producing LGAs may limit the application of the results beyond the specific study area. Data collected during a single season might not capture seasonal variations in climate impacts and dairy production. Additionally, adaptation outcomes were primarily evaluated using composite perception-based measures, and important explanatory variables, such as objective climatic or production records, were not included in the analyses.

5. Conclusions

This study explored factors influencing climate change adaptation among smallholder dairy farmers in Plateau State, Nigeria. Results show that irregular rainfall, increasing temperatures, seasonal feed shortages, declining forage quality, and water scarcity are key obstacles to dairy production and milk yield. While most farmers reported noticing weather changes, overall awareness of climate change was limited, and current adaptation strategies were inadequate to effectively tackle these issues.

Multiple linear regression analysis found that educational attainment, climate change awareness, access to extension services, and feed availability all significantly affect dairy adaptation outcomes. Of these, access to extension services has the strongest impact, highlighting the importance of technical support and information access in boosting farmers' adaptive capacity.

The study identified educational level, climate change awareness, extension service access, and feed availability as significant factors associated with climate change adaptation among the participating smallholder dairy farmers. Although the findings are not statistically generalizable to all dairy farmers in Plateau State because of the sampling design, they provide useful evidence for informing climate-smart livestock interventions in similar smallholder dairy production systems. Future studies employing probability-based sampling across a broader geographic area are recommended to enhance the external validity of these findings.

Author Contributions: Conceptualization, H.I.F. and L.Y.G.; methodology, H.I.F., P.P.B., S.E.D., L.Y.G., S.B.P. and D.Y.G.; software, H.I.F. and L.Y.G.; validation, H.I.F., P.P.B., S.E.D., L.Y.G., S.B.P. and D.Y.G.; formal analysis, H.I.F., P.P.B., S.E.D., L.Y.G., S.B.P. and D.Y.G.; investigation, H.I.F., P.P.B., S.E.D., L.Y.G., S.B.P. and D.Y.G.; resources, H.I.F.; data curation, H.I.F. and L.Y.G.; writing—original draft preparation, H.I.F. and L.Y.G.; writing—review and editing, H.I.F., P.P.B., S.E.D., L.Y.G., S.B.P. and D.Y.G.; visualization, H.I.F., P.P.B., S.E.D., L.Y.G., S.B.P. and D.Y.G.; supervision,

H.I.F.; project administration, H.I.F.; funding acquisition, H.I.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Tertiary Education Trust Fund (TETFund), Nigeria, as part of the Institution-Based Research (IBR) intervention.

Institutional Review Board Statement: Ethical approval for the study was obtained from the Institutional Ethics Review Board of Plateau State University, Boko (Approval number: PLASU/R and D/AA/25/02, Approval date: 17 November 2025). Permission to conduct the survey was also obtained from relevant local authorities, community leaders, and agricultural extension officers within the selected LGAs. Participation was voluntary, and informed consent was obtained from all respondents before data collection. Respondents' confidentiality and anonymity were maintained throughout the study, and all data were used solely for academic and research purposes. Personal identifiers were excluded from the data set, and all procedures complied with internationally accepted ethical principles for research involving human subjects.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: The authors gratefully acknowledge financial support from the Tertiary Education Trust Fund (TETFund), Nigeria, which made this research possible. We also extend our sincere appreciation to our respective institutions, particularly Plateau State University, Boko (PLASU), for providing the institutional support, facilities, and enabling environment necessary for the successful execution of this study.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

IPPC	Intergovernmental Panel on Climate Change
NiMet	Nigerian Meteorological Agency
DAOI	Dairy Adaptation Outcome Index
FAO	Food and Agriculture Organization of the United Nations
LGAs	Local Government Areas
ANOVA	Analysis of variance
FGDs	Focus group discussions
KIIs	Key Information Interviews

References

1. Azarov, A.; Kulikov, M.; Sidle, R.C.; Zaginaev, V. Climate Change and Its Impact on Natural Resources and Rural Livelihoods: Gendered Perspectives from Naryn, Kyrgyzstan. *Climate* **2025**, *13*, 57. <https://doi.org/10.3390/cli13030057>.
2. Abebaw, S.E. A global review of the impacts of climate change and variability on agricultural productivity and farmers' adaptation strategies. *Food Sci. Nutr.* **2025**, *13*, e70260.
3. IPCC (Intergovernmental Panel on Climate Change). Climate Change. Synthesis report. In *Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Geneva, Switzerland, 2023. Available online: <https://www.ipcc.ch/report/ar6/syr/> (accessed on 28 June 2026).
4. FAO (Food and Agriculture Organization of the United Nations). *Climate-Smart Agriculture Sourcebook*, 2nd ed.; FAO: Rome, Italy, 2023. Available online: <https://www.fao.org/climate-smart-agriculture-sourcebook> (accessed on 28 June 2026).
5. Papakonstantinou, G.I.; Voulgarakis, N.; Terzidou, G.; Fotos, L.; Giamouri, E.; Papatsiros, V.G. Precision Livestock Farming Technology: Applications and Challenges of Animal Welfare and Climate Change. *Agriculture* **2024**, *14*, 620. <https://doi.org/10.3390/agriculture14040620>.

6. Thornton, P.K.; Boone, R.B.; Ramirez-Villegas, J.; Herrero, M. Climate change impacts on livestock systems and adaptation options. *Annu. Rev. Anim. Biosci.* **2022**, *10*, 391–413.
7. Herrero, M.; Thornton, P.K.; Mason-D'Croz, D.; Palmer, J.; Bodirsky, B.L. Articulating the effect of climate change on livestock systems. *Glob. Food Secur.* **2021**, *29*, 100488.
8. Mburu, M.; Mugeru, A.; Mburu, J.; Nyikal, R.; Ndambi, O.A. Climate-Smart Dairy Practices: The Role of Practice Clusters in Enhancing the Performance of Dairy Farms in Kenya. *Agribusiness* **2026**, *42*, 717–732.
9. Tadele, E.; Worku, D.; Yigzaw, D.; Muluneh, T.; Melese, A. Precision of dairy farming: Navigating challenges and seizing opportunities for sustainable dairy production in Africa. *Front. Anim. Sci.* **2025**, *6*, 1541838. <https://doi.org/10.3389/fanim.2025.1541838>.
10. Habeeb, A.A.; Osman, S.F.; Teama, F.E.; Gad, A.E. The detrimental impact of high environmental temperature on physiological response, growth, milk production, and reproductive efficiency of ruminants. *Trop. Anim. Hlth Prod.* **2023**, *55*, 388.
11. Nketsang, T.S.; Kassa, S.M.; Kgosimore, M.; Tsidu, G.M. Understanding the Impacts of Rainfall Variability on Natural Forage–Livestock Dynamics in Arid and Semi-Arid Environments. *Appl. Sci.* **2025**, *15*, 3918. <https://doi.org/10.3390/app15073918>.
12. John, C.K.; Pu, J.H. Climate-Driven Water Scarcity and Its Public Health Implications: A Multi-Regional Assessment Across Vulnerable Socio-Ecological Systems. *Water* **2026**, *18*, 699. <https://doi.org/10.3390/w18060699>.
13. Musa, H.H.; Mwacharo, J.M.; Adam, S.Y.; Cai, D.; Ahmed, A.A. Climate change, nutrigenomics, immune function and diseases and production in dairy cattle: A comprehensive review. *Appl. Vet. Res.* **2023**, *2*, e2023010.
14. NiMet (Nigerian Meteorological Agency). *Seasonal Climate Prediction 2024*; Nigerian Meteorological Agency: Abuja, Nigeria, 2024.
15. Ayanlade, A.; Radeny, M.; Morton, J.F. Climate change adaptation among livestock farmers in sub-Saharan Africa: Evidence from Nigeria. *Clim. Dev.* **2022**, *14*, 421–433.
16. Ojo, T.O.; Baiyegunhi, L.J.S.; Adetoro, A.A. Climate variability and livestock productivity among smallholder farmers in Nigeria. *J. Agric. Rural Dev. Trop. Subtrop.* **2021**, *122*, 183–195.
17. Intergovernmental Panel on Climate Change. *Climate Change 2023: Synthesis Report*; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2023.
18. Abdel-Wareth, A.A.A.; Ahmed, A.A.; Taqi, M.O.; Salahudin, M.; Lohakare, J. Artificial Intelligence Applications in Animal Production Systems for Climate Resilience and Sustainability: A Comprehensive Review. *Agriculture* **2026**, *16*, 1146. <https://doi.org/10.3390/agriculture16111146>.
19. Chandrakar, P.; Mahanthesh, M.T.; Abraham, B.L.; Singh, V.P.; Tanpure, M.U.; Tiwari, P.K.; Bara, S. Sustainable Livestock Production Strategies for Climate Adaptation: A Review. *Arch. Curr. Res. Int.* **2025**, *25*, 436–454.
20. Mansour, T.G.I.; Abd El-Ghani, S.S.; Murad, H.S. Farmers' Attitudes Toward Mechanisms and Practices of Climate Change Adaptation in Egypt and Iraq: A Comparative Field Study. *Sustainability* **2026**, *18*, 2502. <https://doi.org/10.3390/su18052502>.
21. Mapiye, C.; Chikwanha, O.C.; Dzama, K. Building resilience in livestock systems under climate change in Africa. *Animals* **2023**, *13*, 1182.
22. Mabhaudhi, T.; Chimonyo, V.G.P.; Chibarabada, T.P.; Modi, A.T. Climate change adaptation and resilience in African agriculture. *Sustainability* **2021**, *13*, 2154.
23. Bao, X.; Zhang, X. Climate Risk Perception and Corporate Green Innovation: From Cognitive Awareness to Behavioral Response. *Sustainability* **2026**, *18*, 752. <https://doi.org/10.3390/su18020752>.
24. Mutenje, M.; Kankwamba, H.; Mangisoni, J. Determinants of climate change adaptation among smallholder farmers in sub-Saharan Africa. *Environ. Dev.* **2020**, *35*, 100520.
25. NBS (National Bureau of Statistics), Overview of GDP in Quarter One, 2023. Retrieved July 20, 2026. Available online: <https://nigerianstat.gov.ng> (accessed on 28 June 2026).
26. DfID (Department for International Development). *Sustainable Livelihoods Guidance Sheets*; DFID: London, UK, 1999; Volume 445, p. 710.
27. Yamane, T. *Statistics: An Introductory Analysis*, 2nd ed.; Harper & Row: New York, NY, USA, 1967.
28. IBM Corp. *IBM SPSS Statistics for Windows*, Version 29.0.; IBM Corp: Armonk, NY, USA, 2022.
29. Abdulazeez, M.A.; Abdulrahman, O.; Olooto, F.M. Assessment of Male and Female Participation in Livestock Group Activities in Kwara State, Nigeria. *FUDMA J. Agric. Agric. Technol.* **2026**, *12*, 62–68.
30. Galiè, A.; Ojango, J.M.; Farnworth, C.R.; Jumba, H.; Roeven, L.; Marshall, K. Building gender considerations into livestock breeding in low-and middle-income countries. *Front. Anim. Sci.* **2025**, *6*, 1511992.
31. Barasa, D.M.; Adolwa, I.; Abubakari, M.; Kavise, B.; Limo, B.; Pali, P.N. Understanding farmer decision-making and gendered adoption strategies under climate shocks in sub-Saharan Africa. *Front. Sustain. Food Syst.* **2026**, *10*, 1676698.

32. Mosha, N.F.V.; Ngulube, P. Adoption of climate change mitigation and adaptation strategies among smallholder farmers in African countries: A systematic review. *Discov. Sustain.* **2025**, *6*, 1087.
33. Sun, Y.; Li, Q.; Liu, H. Factors influencing agricultural digital transformation: A systematic review of environmental, technological, and individual dimensions. *Comput. Electron. Agric.* **2026**, *244*, 111430.
34. Ewulo, T.A.; Akinseye, F.M.; Teme, N.; Agele, S.O.; Yessoufou, N.; Kumar, S. Factors driving Climate-Smart Agriculture adoption: A study of smallholder farmers in Koumpentum, Senegal. *Front. Agron.* **2025**, *7*, 1552720.
35. Arangurí, M.; Mera, H.; Noblecilla, W.; Lucini, C. Digital Literacy and Technology Adoption in Agriculture: A Systematic Review of Factors and Strategies. *AgriEngineering* **2025**, *7*, 296. <https://doi.org/10.3390/agriengineering7090296>.
36. Postigo, J.C.; Mamani, M.Q. Understanding local knowledge production to address global environmental change: Leveraging the case of Bolivian Aymara expert farmers. *Reg. Environ. Change* **2026**, *26*, 23.
37. Novak, A.; Šumrada, T.; Juvančič, L.; Sutherland, L.A. The ‘Good Farmer’ and nature conservation through the eyes of agricultural advisors: Insights from Slovenia. *Agric. Hum. Values* **2026**, *43*, 18.
38. Akintan, O.A.; Gebremedhin, K.G.; Uyeh, D.D. Linking Animal Feed Formulation to Milk Quantity, Quality, and Animal Health Through Data-Driven Decision-Making. *Animals* **2025**, *15*, 162. <https://doi.org/10.3390/ani15020162>.
39. Akintan, O.; Gebremedhin, K.G.; Uyeh, D.D. Animal Feed Formulation—Connecting Technologies to Build a Resilient and Sustainable System. *Animals* **2024**, *14*, 1497.
40. Danna, M.; Scheeren, F.B.; Luz, J.H.S.d.; Menezes, L.F.G.d.; Paris, W.; Amadori, C.; Andriotti, N.; Garrett, C.E.; Putti, F.F.; Sartor, L.R. Animal Supplementation and Legume Pastures Enhance Nitrogen Balance and Efficiency in Integrated Crop-Livestock Systems. *Agriculture* **2025**, *15*, 2394. <https://doi.org/10.3390/agriculture15222394>.
41. Kennedy, R.; Moloney, A.P.; O’Riordan, E.G.; Kelly, A.K.; McGee, M. Intake, Growth and Carcass Traits of Steers Offered Grass Silage and Concentrates Based on Contrasting Cereal Grain Types Supplemented with Field Beans, Peas or Maize By-Products. *Animals* **2023**, *13*, 1209. <https://doi.org/10.3390/ani13071209>.
42. Conte, G.; Ciampolini, R.; Cassandro, M.; Emiliano, L.; Calamari, L.; Bernabucci, U.; Abeni, F. Feeding and nutrition management of heat-stressed dairy ruminants. *Ital. J. Anim. Sci.* **2018**, *17*, 604–620.
43. West, J.W. Effects of Heat-Stress Production in Dairy Cattle. *J. Dairy Sci.* **2003**, *86*, 2131–2144.
44. Onan-Martinez, D.; de Bari, M.; Olmo, H.; Vyas, D.; de Guzmán, C.N.; Santos, J.; Lance, J.; Toledo, I.; Tricarico, J.; Dahl, G. Heat stress increases enteric methane emissions yield and intensity while impairing rumen function and productivity in lactating dairy cattle. *J. Dairy Sci.* **2026**, *109*, 5101–5111.
45. Park, T.; Ma, L.; Gao, S.; Bu, D.; Yu, Z. Heat stress impacts the multi-domain ruminal microbiota and some of the functional features independent of its effect on feed intake in lactating dairy cows. *J. Anim. Sci. Biotechnol.* **2022**, *13*, 71. <https://doi.org/10.1186/s40104-022-00717-z>.
46. Yadav, B.; Singh, G.; Wankar, A.; Dutta, N.; Chaturvedi, V.B.; Verma, M.R. Effect of simulated heat stress on digestibility, methane emission and metabolic adaptability in crossbred cattle. *Asian-Australas. J. Anim. Sci.* **2016**, *29*, 1585.
47. Czaplicki, S.; Hornick, J.-L.; Besserve, N.; Dumont Saint Priest, B.; Lessire, F.; Bartholomé, H.; Dufrasne, I. In Vitro Screening of Feed Additives for Maintaining Ruminal Fermentation Levels Under Heat Stress. *Dairy* **2026**, *7*, 40. <https://doi.org/10.3390/dairy7030040>.
48. Chen, L.; Thorup, V.M.; Kudahl, A.B.; Østergaard, S. Effects of heat stress on feed intake, milk yield, milk composition, and feed efficiency in dairy cows: A meta-analysis. *J. Dairy Sci.* **2024**, *107*, 3207–3218.
49. Abubakar, A.; Magaji, S.; Ismail, Y. Climate Crunch: Coping with Climate Change in Irrigated Agriculture in Dutse, Jigawa, Nigeria. *Int. J. Innov. Sci. Res. Technol.* **2025**, *10*, 651–660.
50. Arshad, M.W.; Moazzam, M.; Raziq, M.M.; Ahmed, W. Linking the willingness of smallholder dairy farmers to adopt minimum food safety and quality standards to the country’s export potential. *Int. J. Food Sci. Technol.* **2023**, *58*, 5557–5567.
51. Korale-Gedara, P.; Weerahewa, J.; Roy, D. Food safety in milk: Adoption of food safety practices by small-scale dairy farmers in Sri Lanka and their determinants. *Food Control* **2023**, *143*, 109274.
52. Finizola e Silva, M.; Van Schoubroeck, S.; Cools, J.; Van Passel, S. A systematic review identifying the drivers and barriers to the adoption of climate-smart agriculture by smallholder farmers in Africa. *Front. Environ. Econ.* **2024**, *3*, 1356335.
53. Food and Agriculture Organization. *The State of Food and Agriculture 2023: Climate-Smart Agriculture for Sustainable Food Systems*; Food and Agriculture Organization: Rome, Italy, 2023.
54. Antwi-Agyei, P.; Stringer, L.C. Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. *Clim. Risk Manag.* **2021**, *32*, 100304.

55. Nyasimi, M.; Kimeli, P.; Sayula, G.; Radeny, M.; Kinyangi, J.; Mungai, C. Adoption and Dissemination Pathways for Climate-Smart Agriculture Technologies and Practices for Climate-Resilient Livelihoods in Lushoto, Northeast Tanzania. *Climate* **2017**, *5*, 63. <https://doi.org/10.3390/cli5030063>.
56. Shrestha, R.; Kadel, R.; Shakya, S.; Nyachhyon, N.; Mishra, B.K. Awareness and Understanding of Climate Change for Environmental Sustainability Using a Mix-Method Approach: A Study in the Kathmandu Valley. *Sustainability* **2025**, *17*, 2819. <https://doi.org/10.3390/su17072819>.
57. Cai, Y.; Zhao, M.; Khan, A.; Shi, Y. Understanding herder's perception and adaptation to climate change: An integrated framework. *Environ. Dev. Sustain.* **2025**, *27*, 30089–30117.
58. O'Neill, B.C.; Jiang, L.; Kc, S.; Fuchs, R.; Pachauri, S.; Laidlaw, E.K.; Zhang, T.; Zhou, W.; Ren, X. The effect of education on determinants of climate change risks. *Nat. Sustain.* **2020**, *3*, 520–528.
59. Osumba, J.J.L.; Recha, J.W.; Oroma, G.W. Transforming Agricultural Extension Service Delivery through Innovative Bottom-Up Climate-Resilient Agribusiness Farmer Field Schools. *Sustainability* **2021**, *13*, 3938. <https://doi.org/10.3390/su13073938>.
60. Dooley, K.E.; Grady Roberts, T. Agricultural education and extension curriculum innovation: The nexus of climate change, food security, and community resilience. *J. Agric. Educ. Ext.* **2020**, *26*, 1–3.
61. Chaidanya, K.; Shaji, S.; Niyas, P.A.; Sejian, V.; Bhatta, R.; Bagath, M.; Rao, G.; Kurien, K.; Varma, G. Climate change and livestock nutrient availability: Impact and mitigation. *J. Vet. Sci. Med. Diagn.* **2015**, *4*, 3. <http://doi.org/10.4172/2325-9590.1000160>.
62. Henry, B.K.; Eckard, R.J.; Beauchemin, K.A. Adaptation of ruminant livestock production systems to climate changes. *Animal* **2018**, *12*, s445–s456.
63. Martin, G.; Magne, M.A. Agricultural diversity to increase adaptive capacity and reduce vulnerability of livestock systems against weather variability—A farm-scale simulation study. *Agric. Ecosyst. Environ.* **2015**, *199*, 301–311.
64. Slayi, M.; Zhou, L.; Nyambo, P.; Jaja, I.F.; Muchaku, S. Communally established cattle feedlots as a sustainable livelihood option for climate change resilience and food security in sub-Saharan Africa: A systematic review. *Front. Sustain. Food Syst.* **2024**, *7*, 1325233.
65. Adesogan, A.T.; Gebremikael, M.B.; Varijakshapanicker, P.; Vyas, D. Climate-smart approaches for enhancing livestock productivity, human nutrition, and livelihoods in low-and middle-income countries. *Anim. Prod. Sci.* **2025**, *65*. <https://doi.org/10.1071/AN24215>.
66. Karki, S.; Burton, P.; Mackey, B. The experiences and perceptions of farmers about the impacts of climate change and variability on crop production: A review. *Clim. Dev.* **2020**, *12*, 80–95.
67. Chimi, P.M.; Mala, W.A.; Fobane, J.L.; Nganmeni, L.F.F.; Medoh, J.; Abdel, K.N.; Nkoué, B.B.; Minfele, S.P.E.; Funwi, F.P.; Kamdem, M.E.K.; et al. Socioeconomic determinants of climate change perceptions and adaptive responses among smallholder farmers in Mbangassina in Cameroon. *Discov. Sustain.* **2026**, *7*, 704. <https://doi.org/10.1007/s43621-026-03140-w>.
68. Duong, T.T.; Lebailly, P.; Truong, Q.T.; Ho, H.T.M.; Burny, P. Livelihood impact of alternative crop adoption under climate stress: A meta-analysis. *Front. Sustain. Food Syst.* **2026**, *10*, 1843082.
69. Filho, W.L.; Totin, E.; Roncoli, C.; Dlamini, L.; North, M.A.; Rudden, W.; Ayimasse, A.F.; Assogba, F.J.; Zoundji, G.C.; Trisos, C.H. Climate change and food production in Africa: What do we know about climate related losses and damages, and adaptation responses? *Clim. Dev.* **2026**, 1–11. <https://doi.org/10.1080/17565529.2026.2623641>
70. Maninga, F.; Sichula, N.K. Climate Literacy and Adaptation Strategies among the Small-Scale Farmers in Chongwe District of Zambia. *J. Environ. Clim. Ecol.* **2026**, *3*, 52–62.
71. Bai, Q.; Li, J.; Zhang, J.; Zang, D.; Zhang, K.; Shen, Q. Does digital literacy promote the climate disaster adaptive production behavior of grain smallholders in China? *J. Integr. Agric.* **2025**, *26*, 2214–2228.
72. Anshul, A.; Mitesh, S.; Srinivasan, G.; Buizer, J.; Finan, T.; Singh, K.K.; Kumar, S. Integrating climate information into decision making for building resilience: A case study on farming communities in Bihar, India. *Clim. Serv.* **2022**, *28*, 100328.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.