Research Article

# Climate Risk Perception and Practice Adoption Among Ruminant Farmers in Arid Jordan

**Mohammed N. Sawalhah[1,2]*, Mysaa A. Ata[3], Mohammad S. Altarawneh[4], Mabrouk R. Elsabagh[2], Fatima A. Al-Lataifeh[3], Tariq M. Hatamleh[5]**

*[1]Department of Land Management and Environment, Prince El-Hassan Bin Talal Faculty for Natural Resources and Environment, The Hashemite University, P.O. Box 330127, Zarqa 13133, Jordan; [2]College of Agriculture, University of Al Dhaid, Al-Dhaid, Sharjah, United Arab Emirates; [3]Department of Animal Production and Protection, Faculty of Agriculture, Jerash University, Jerash 26150, Jordan; [4]Department of Agricultural Economics and Extension, Faculty of Agriculture, Jerash University, Jerash 26150, Jordan; [5]National Agricultural Research Center, Al-Khanasiri Livestock and Pasture Research Station. Mafraq, Jordan.*

**Abstract** | The livestock sector, particularly ruminant production, both contributes to greenhouse gas emissions and highly vulnerable to climate change, especially in arid northern Jordan where it underpins food security and livelihoods. This study assessed climate change risk perception and the adoption of adaptation and mitigation practices among 224 ruminant farmers in Ajloun, Irbid, Mafraq, and Jerash governorates. A structured questionnaire was implemented, and data were analyzed in SPSS using descriptive and inferential statistics. Three composite indices were constructed: Climate Risk Perception, Adaptation Practices, and Mitigation Practices. All indices showed high internal consistency ($\alpha$=0.80–0.86) and high mean scores (3.97–4.19 on 5-point scale), indicating strong agreement with statements about climate-related risks and self-reported performance of sustainable practices. Perceived risks were particularly high for heat stress, feed and water shortages, increased disease, and rising feed prices. Adaptation measures centered on housing and microclimate management, vaccination programs, and use locally adapted breeds, while feeding high-concentrate diets was less commonly adopted. Mitigation practices such as improved manure management and reducing stocking were widely implemented, but rotational grazing was relatively underused. Indices were positively correlated; larger farms adopted more adaptations, while experience showed negative associations. Farmers with veterinary access had significantly higher mitigation scores, and sheep/goat farmers reported higher risk perception and greater acceptance of the adaptation and mitigation practices than cattle farmers. The findings highlight both the strengths and gaps in current climate-smart livestock practices in northern Jordan and point to the need for targeted extension, veterinary support, and policy incentives to expand sustainable production systems.

**Keywords** | Climate-smart agriculture, ruminant farming, adaptation strategies, mitigation practices, arid regions

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***Correspondence** | Mohammed N. Sawalhah, College of Agriculture, University of Al Dhaid, 7W86+8HP - Al Sidra, Al Dhaid - Sharjah, United Arab Emirates; **Email:** mohammed.sawalhah@uodh.ac.ae, sawalhah@hu.edu.jo
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## INTRODUCTION

Agriculture occupies a dual position in the climate change debate; it is both a major source of greenhouse gas (GHG) emissions and one of the sectors most exposed to climate-related shocks (Li and Huang, 2023). Livestock systems, particularly ruminant production, sit at the center of this dilemma. They contribute significantly to global emissions through enteric methane, manure management, and feed production, while simultaneously facing escalating risks from heat stress, feed and water scarcity, and emerging diseases (Rojas-Downing *et al*., 2017; Thornton *et al*., 2009).

Global assessments suggest that the livestock sector accounts for a substantial share of anthropogenic GHG emissions, with ruminants responsible for the bulk of methane and nitrous oxide emissions from animal agriculture (Opio *et al*., 2013; Sejian *et al*., 2016). Enteric fermentation alone is estimated to contribute around a quarter of global methane emissions (Nwobodo *et al*., 2022). As demand for animal-source foods continues to grow, particularly in developing regions, the challenge is to sustain production while reducing the sector's climate footprint and safeguarding ecosystem integrity (Pretty and Bharucha, 2014; Zhang *et al*., 2017). At the same time, sustainable livestock production is increasingly viewed as a cornerstone of climate-resilient food systems. The concept of sustainable intensification emphasizes increasing or stabilizing yields without expanding agricultural land and without incurring further environmental damage (Pretty and Bharucha, 2014). In the livestock sector, this associated with adaptation and mitigation strategies, including improved housing and microclimate management, better nutrition and health care, use of resilient breeds, manure and pasture management, and integration with crops and trees (Henry *et al*., 2012; de Boer *et al*., 2011; Hoque *et al*., 2022; Rojas-Downing *et al*., 2017).

Climate change already exerts multiple direct and indirect impacts on ruminant systems. Elevated temperatures and heat waves reduce feed intake, growth, milk yield, and reproductive performance, while also increasing mortality risk (Rojas-Downing *et al*., 2017; Ben Moula *et al*., 2024). Shifts in rainfall patterns and more frequent droughts diminish pasture quantity and quality, tighten water availability, and drive rangeland degradation (Sejian, 2013; Joy *et al*., 2020). Warmer and more variable climates also favor the spread of vector-borne and infectious diseases, with consequences for animal welfare, productivity, and food safety (Khan, 2015; Ashraf *et al*., 2017).

In the Middle East and North Africa, livestock systems are particularly sensitive to climate shocks because they often operate in arid and semi-arid environments with limited water, fragile rangelands, and strong competition over natural resources (van de Steeg and Tibbo, 2012). Jordan exemplifies these challenges. Small-ruminant production is central to rural livelihoods, especially in northern and eastern governorates, yet is constrained by recurrent droughts, high feed costs, and land-use competition (Al-Barakeh *et al*., 2024; Awad *et al*., 2024). Recent studies in northern Jordan document high dependence on Awassi sheep and Baladi goats, mixed crop–livestock systems, and heavy reliance on family labor, with climate variability exacerbating water and forage limitations (Al-Barakeh *et al*., 2024).

Against this backdrop, climate-smart agriculture and sustainable production practices have gained prominence as policy priorities in Jordan. National initiatives and donor-supported programs aim to strengthen resilience through water-efficient technologies, rangeland restoration, and support to smallholders (Hoque *et al*., 2022). However, the actual adoption of sustainable practices at farm level depends on a complex interplay of socio-economic characteristics, risk perception, institutional support, and local knowledge (Ata *et al*., 2021; Karimi *et al*., 2018; Knowler and Bradshaw, 2007). A study by Nwobodo *et al*. (2022) showed that farmers use of sustainable production practices for climate change adaptation and mitigation in Enugu State, Nigeria, is strongly shaped by factors such as access to veterinary services, income, and knowledge. Yet comparable evidence from arid regions especially in the Middle East remains very limited, even though these areas face some of the most intense climate pressures on ruminant systems. Understanding how farmers in these dryland contexts perceive climate risks and which practices they adopt is essential for designing interventions that are realistic, effective, and locally grounded.

In this study, we therefore focus on describing the socio-economic profile of ruminant farmers in northern Jordan and explore how they perceive climate-related risks in their own production systems. In addition, we examine how farmers translate climate risk perceptions into reported management responses, by analyzing the associations between risk perception and the adoption of adaptation and mitigation practices, alongside key socio-economic and production factors.

## MATERIALS AND METHODS

### Study area and population

This study was conducted in the northern region of Jordan, specifically in Ajloun, Irbid, Mafraq, and Jerash Governorates (Figure 1). The region is characterized by an arid climate with significant daily and seasonal temperature variations. The study population consisted of ruminant farmers in the area, categorized into two groups: Small ruminant farmers and large ruminant farmers (N= 629). A representative sample of 224 ruminant farmers was selected randomly to ensure proportional representation from both production groups. All distributed questionnaires were successfully retrieved, resulting in a complete response rate. The sample size was determined using Yamane's (1967) simplified formula for finite populations, applying an error level of e = 0.05, which allowed for an efficient estimation while maintaining statistical reliability for survey-based research.

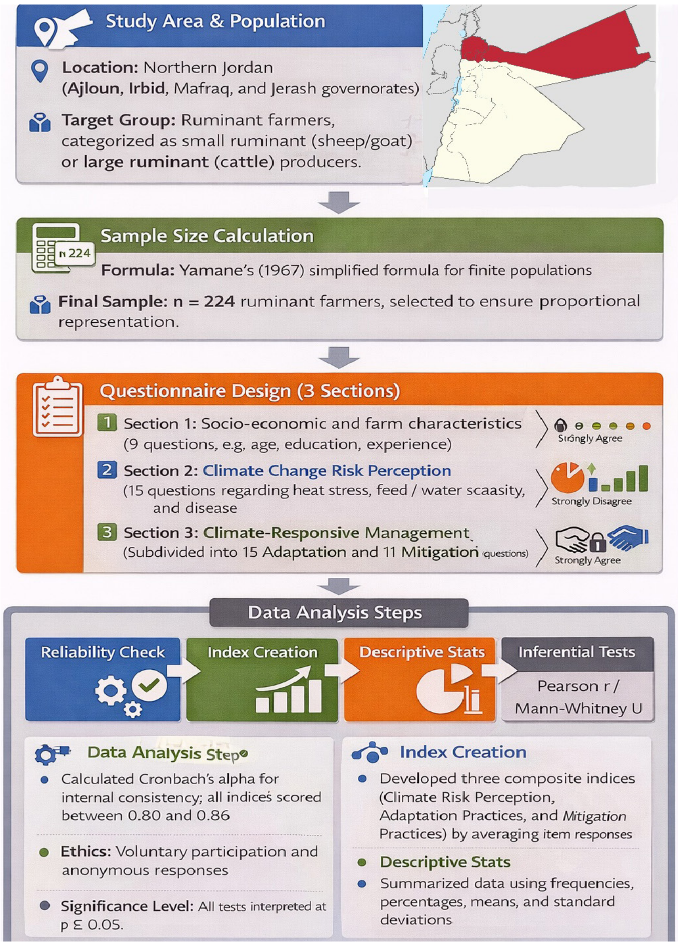


**Figure 1:** Flowchart of study area and methodology.

## Study design and data collection

This study employed a cross-sectional survey design using a structured questionnaire and used both secondary and primary data sources. Secondary data were obtained from official reports and publications by the Ministry of Agriculture (MOA) and the Department of Statistics (DOS), as well as from agricultural directorates in the study area. These sources provided contextual background on the agricultural landscape and climate-related challenges faced by ruminant farmers.

Primary data were collected using a structured questionnaire developed in consultation with animal production experts to ensure content validity. The questionnaire was designed to assess farmers' adaptation and mitigation strategies in response to climate change, with a focus on sustainable production practices. Participation in the survey was voluntary, and all responses were collected anonymously.

The questionnaire comprised both closed and open-ended questions and was structured into three main sections. The first section included nine questions capturing key demographic characteristics such as age, gender, educational attainment, and years of experience in ruminant farming. The second section consisted of 15 questions assessing farmer's perceptions of climate change risks, focusing on reported impacts related to heat stress, feed and water availability, pasture quantity and quality, disease incidence, animal mortality, fertility, growth performance, milk yield and quality, and fluctuations in feed and feed-additive prices. The third section addressed farmer's climate-responsive management strategies and was divided into two sub-sections: 15 questions measuring adoption of adaptation practices and 11 questions measuring mitigation practices. Adaptation measures included shade provision, improved ventilation, stocking rate adjustment, use of heat- or disease-resistant and locally adapted breeds, vaccination and treatment programs, feed storage, diet modification, enhanced water access, crop diversification, early forage harvesting, rotational grazing or relocation, and crossbreeding. Mitigation practices encompassed tree planting, manure management, providing floor bedding during cold periods, dietary supplementation, drainage maintenance, rotational grazing, protecting vegetative cover, cooling manure areas, utilizing essential oils, feed diversification, and reducing stocking density (Figure 1).

## Data analysis

The collected data were analyzed using SPSS Statistics (Version 20.0). A 5-point Likert scale was used to measure farmers' perceptions and adoption of sustainable practices, with responses ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

Cronbach's alpha coefficients were calculated for each section to assess questionnaire reliability. Scales with coefficients above 0.70 were considered sufficiently reliable for analysis. Composite scores were then computed by averaging the responses across items within each construct, and these scores were used in subsequent correlation and comparative analyses. Any missing values were treated as system-missing and excluded pairwise from all relevant analyses.

Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize the data. For inferential analysis, although individual questionnaire items were measured on an ordinal Likert scale, composite indices were calculated by averaging multiple items and were treated as quasi-continuous variables, allowing the use of Pearson's correlation analysis. Prior to inferential analysis, the distributional properties of the three composite indices were evaluated. Although individual socio-economic variables such as farm size exhibited positive skewness, the averaged indices demonstrated distributions suitable for Pearson's correlation analysis. This quasi-continuous treatment is supported by the high internal reliability (Cronbach's α ≥ 0.80) and a sample size of n=224. For categorical group comparisons, where the risk of violating parametric assumptions is higher, non-parametric Mann–Whitney U tests were applied to ensure the statistical validity of the findings. Therefore, Pearson's correlation coefficient (r) was used to examine relationships between the composite indices and other continuous variables. When analyzing associations between Likert-scale variables and categorical variables (such as farmer type), appropriate non-parametric tests (Mann–Whitney U) were applied to account for the ordinal nature of the data (Figure 1).

All statistical tests were interpreted at a significance level of $p \leq 0.05$. These analytical procedures were used to assess the adoption of sustainable production practices among ruminant farmers and to identify factors influencing their adaptation and mitigation strategies in response to climate change.

## RESULTS

### Socio-economic and farm characteristics

Respondents were predominantly middle-aged, with a mean age of approximately 49 years and a relatively narrow age range. Farming and ruminant-farming experience were both high, averaging more than 20 years, indicating that most respondents were long-term practitioners. Farm size and annual income from ruminant production were highly variable and positively skewed, with median farm size of 50 dunums (IQR: 12–250) and median annual income of 1,500 JOD (IQR: 675–2,675), reflecting the coexistence of smallholders with relatively modest landholdings and a few large operations holding up to 1,000 dunums and generating up to 40,000 JOD annually (Table 1).

**Table 1:** Descriptive statistics of socio-economic characteristics of surveyed ruminant farmers in northern Jordan (n = 224).

| Variable | Mean ± SD | Median | IQR | Range |
|---|---|---|---|---|
| Age (years) | 48.77 ± 7.68 | 49 | 44-55 | 23–65 |
| General farming experience (years) | 23.58 ± 11.10 | 23 | 15-30 | 3–53 |
| Specific ruminant farming experience (years) | 20.96 ± 11.92 | 20 | 10-29.5 | 1–53 |
| Farm size (dunums) | 166.45 ± 243.41 | 50 | 12–250 | 1–1000 |
| Income from ruminant farming (JOD/year) | 2108.63± 3550.82 | 1500 | 675–2675 | 85–40,000 |

The sample consisted mainly of male farmers (79.02%), and a majority reported having at least some formal education (69.64%). About two-thirds of respondents indicated access to veterinary services, and most were sheep/goat producers (72.32%)., with cattle keepers representing a smaller share of the sample. These characteristics are broadly consistent with other descriptions of small-ruminant production systems in northern and arid regions of Jordan (Al-Barakeh *et al*., 2024; Awad *et al*., 2024) (Table 2).

**Table 2:** Distribution of socio-economic and farm characteristics of surveyed ruminant farmers in northern Jordan (n= 224).

| Variable | Category | Percent (%) * |
|---|---|---|
| Gender | Male | 79.02 |
| | Female | 20.98 |
| Education | Educated | 69.64 |
| | Uneducated | 28.57 |
| | Missing | 1.79 |
| Availability of veterinary services | Available | 66.07 |
| | Unavailable | 33.04 |
| | Missing | 0.89 |
| Type of ruminants kept | Cattle | 27.68 |
| | Sheep/Goats | 72.32 |

* Percentages may not sum to 100% due to rounding.

### Climate-related indices

The three climate related indices (climate risk perception, adaptation practices, and mitigation practices) exhibited good to excellent internal consistency. Cronbach's alpha values ranged from 0.80 for the mitigation index to 0.86 for the climate risk perception index, as shown in Table 3. These values exceed the commonly accepted threshold (Cronbach's α = 0.7) for group-level research and support the use of mean scores as indices of climate risk perception, adaptation practices, and mitigation practices (Cortina, 1993).

**Table 3:** Reliability estimates for climate-related perception and adaptation scales among surveyed ruminant farmers in northern Jordan (n= 224).

| Index | Cronbach's α | Number of questions |
|---|---|---|
| Climate risk perception | 0.86 | 15 |
| Adaptation practices | 0.83 | 15 |
| Mitigation practices | 0.80 | 11 |

All three climate related indices (climate risk perception, adaptation practices, and mitigation practices) had high mean scores, close to 4 on the 5-point Likert scale. This indicates that, on average, farmers tended to agree or strongly agree with most statements relating to climate risks and to their use of adaptation and mitigation measures. Specifically, the mean for climate risk perception was just below 4.0 (3.97±0.49), while adaptation and mitigation means were slightly higher, around 4.19±0.33 and 4.14±0.37, respectively.

### Climate risk perception

Farmers exhibited a consistently high level of concern regarding climate-related risks, spanning both environmental and economic dimensions. Nearly 90% of respondents agreed that their animals experience heat stress, and similarly large majorities reported declines in feed and water availability, deterioration in pasture quality, and increases in disease incidence as major climate-driven challenges. Perceived increases in feed and feed-additive prices were also widely acknowledged. In contrast, only about half of the farmers agreed or strongly agreed that climate change had affected animal growth rate, milk yield, or milk quality, with noticeably lower mean scores for these productivity-related items compared with environmental stressors and disease pressures. This pattern suggests that farmers more readily recognize visible stressors and rising input costs than they explicitly associate climate conditions with changes in production performance (Table 4).

**Table 4:** Distribution of climate risk perception scores on a 5-point Likert scale for ruminant farmers in northern Jordan (n = 224).

| Climate risk perception | Mean ± SD | % ≥4 (Agree/ Strongly Agree) | % =5 (Strongly Agree) |
|---|---|---|---|
| Animals exposed to heat stress | 4.3 ± 0.5 | 99.1 | 27.7 |
| Reduced feed intake | 4.1 ± 0.6 | 94.6 | 19.2 |
| Decreased growth rate | 3.3 ± 1.2 | 51.8 | 19.6 |
| Reduced milk production | 3.4 ± 1.2 | 54.5 | 21.0 |
| Decline in milk quality | 3.3 ± 1.2 | 53.6 | 18.3 |
| Less feed/pasture availability | 4.1 ± 0.8 | 89.7 | 25.9 |
| Less water availability | 4.2 ± 0.6 | 94.2 | 25.0 |
| Lower pasture quality | 4.3 ± 0.5 | 98.2 | 30.8 |
| More disease incidence | 4.3 ± 0.5 | 99.1 | 31.7 |
| Changes in pest distribution | 4.2 ± 0.7 | 92.4 | 34.4 |
| Higher mortality | 4.0 ± 1.0 | 82.1 | 33.9 |
| Lower meat quality | 3.8 ± 1.0 | 75.9 | 23.7 |
| Reduced fertility | 4.0 ± 1.0 | 80.8 | 31.3 |
| Higher feed/additive prices | 4.3 ± 0.7 | 95.5 | 38.0 |
| Animals exposed to cold stress | 4.2 ± 0.8 | 88.0 | 35.3 |

### Adaptation practices

Farmers reported widespread adoption of a broad range of recommended climate adaptation measures (Table 5). Practices aimed at improving housing and microclimate, such as providing shade, ensuring adequate ventilation, and reducing stocking density, were adopted by all farmers. Similarly, vaccination programs, provision of clean drinking water, and the storage of hay, straw, or silage were commonly implemented, reflecting strong alignment with climate-smart management strategies for systems facing heat stress and feed scarcity. Many farmers also indicated reliance on locally adapted or disease-resistant breeds, further demonstrating a proactive approach to enhancing herd resilience. In contrast, feeding high-concentrate diets stood out as the least adopted measure, exhibiting the lowest mean score and the smallest proportion of farmers agreeing or strongly agreeing with its use. less than half (45.5%) of respondents endorsed this practice, suggesting reluctance potentially linked to feed costs, perceived risks, or established production norms. Overall, the Adaptation Practices Index (~ 4.19) reflects a high level of engagement with practical and context-appropriate adaptation strategies across the surveyed farming community.

**Table 5:** Distribution of adaptation practices scores on a 5-point Likert scale for ruminant farmers in northern Jordan (n = 224).

| Adaptation Practices | Mean ± SD | % ≥4 (Agree/ strongly agree) | % =5 (Strongly agree) |
|---|---|---|---|
| Providing shade | 4.4 ± 0.5 | 100.0 | 36.6 |
| Proper ventilation | 4.3 ± 0.5 | 100.0 | 33.9 |
| Reducing animal density | 4.3 ± 0.5 | 100.0 | 33.9 |
| Heat-resistant breeds | 4.3 ± 0.5 | 98.2 | 29.0 |
| Disease-resistant breeds | 4.2 ± 0.5 | 96.4 | 28.6 |
| Providing vaccines/treatments | 4.3 ± 0.5 | 97.8 | 28.1 |
| Storing feed (hay/straw/silage) | 4.1 ± 0.6 | 95.1 | 22.8 |
| Feeding high-concentrate diets | 3.1 ± 1.1 | 45.5 | 13.0 |
| Providing ample clean water | 4.3 ± 0.6 | 96.9 | 36.6 |
| Using locally adapted breeds | 4.4 ± 0.5 | 99.1 | 37.5 |
| Following vaccination programs | 4.4 ± 0.5 | 100.0 | 35.7 |
| Cultivating diverse crops | 4.3 ± 0.6 | 94.6 | 31.1 |
| Harvesting forage early | 4.1 ± 0.8 | 86.9 | 26.1 |
| Rotational grazing/relocation | 4.1 ± 0.7 | 92.0 | 25.9 |
| Crossbreeding resistant breeds | 4.3 ± 0.5 | 97.3 | 28.1 |

### Mitigation practices

Farmers also reported substantial engagement with climate change mitigation practices, with most measures showing high levels of adoption (Table 6). Commonly implemented actions included tree planting around animal shelters, routine removal of manure, maintenance of drainage systems, and the use of dietary supplements or diversified feed sources. These practices are widely recognized for their potential to reduce emissions intensity by improving feed efficiency, limiting methane and nitrous oxide generation from manure, and enhancing the overall environmental conditions of livestock systems (Haque, 2018; Sejian *et al*., 2016). Reducing stocking density and maintaining clean, well-drained pens were similarly prevalent, reflecting an emphasis on both environmental hygiene and climate-smart management. In contrast, rotational grazing emerged as the least adopted mitigation measure. Although approximately two-thirds of farmers expressed agreement with this practice, its mean score, and the proportion of strongly agreeing respondents were noticeably lower than for other mitigation strategies. This pattern is notable given the well-documented capacity of rotational and managed grazing systems to enhance pasture resilience, improve soil carbon sequestration, and increase water-use efficiency (Henry *et al*., 2012; Pretty and Bharucha, 2014). The comparatively modest uptake likely reflects structural and institutional constraints such as land fragmentation, insecure tenure, labor demands, and limited technical guidance that restrict the implementation of landscape-level grazing strategies. Overall, the Mitigation Practices Index (~ 4.14) indicates that while farmers are actively employing several mitigation-oriented practices, significant opportunities remain to expand adoption of more complex, system-wide approaches with higher mitigation potential.

### Relationships among climate-related indices and socio-economic factors

Significant associations ($p < 0.001$) were found among the three climate-related indices. Farmers reporting higher climate risk perception also tended to adopt more adaptation measures, as reflected in a moderately strong correlation between the climate risk perception and the adaptation practices (r= 0.58). Adaptation and mitigation behaviors also co-occurred, with a strong positive correlation between the adaptation practices and the mitigation practices (r= 0.63). The association between climate risk perception and mitigation practices was positive but weaker (r= 0.30), suggesting that mitigation behaviour may depend additionally on resource availability, institutional support, or incentives beyond perceived risk alone (Table 7).

**Table 6:** Distribution of mitigation practices scores on a 5-point Likert scale for ruminant farmers in northern Jordan (n = 224).

| Mitigation practices | Mean ± SD | % ≥4 (Agree/ strongly sgree) | % =5 (Strongly agree) |
|---|---|---|---|
| Planting trees around shelters | 4.2 ± 0.6 | 96.9 | 21.9 |
| Reducing manure storage time | 4.2 ± 0.5 | 97.3 | 24.6 |
| Floor bedding in cold days | 4.2 ± 0.6 | 95.5 | 27.7 |
| Use of dietary supplements | 4.3 ± 0.5 | 97.3 | 29.0 |
| Maintaining drainage systems | 4.2 ± 0.6 | 96.4 | 25.9 |
| Rotational grazing systems | 3.7 ± 1.0 | 67.9 | 17.4 |
| Maintaining vegetative cover | 4.1 ± 0.6 | 94.6 | 20.1 |
| Cooling manure storage areas | 4.1 ± 0.7 | 94.2 | 24.6 |
| Adding essential oils to diets | 4.1 ± 0.7 | 88.8 | 25.9 |
| Diversifying animal feed | 4.2 ± 0.6 | 95.5 | 29.0 |
| Reducing stocking density | 4.3 ± 0.6 | 96.4 | 29.9 |

Socio-economic variables showed distinct and informative patterns. Experience-related variables were consistently and negatively associated with all three indices. Farming experience showed correlations ranging from −0.23 to −0.28, while ruminant farming experience showed even stronger negative relationships (−0.34 to −0.27).

**Table 7:** Relationships between climate risk perception, adaptation practices, mitigation practices, and socio-economic characteristics of ruminant farmers in northern Jordan (n = 224).

| Variable / index | Climate risk perception | Adaptation practices | Mitigation practices |
|---|---|---|---|
| Climate Risk Perception | — | r = 0.58*** | r = 0.30*** |
| Adaptation Practices | r = 0.58*** | — | r = 0.63*** |
| Mitigation Practices | r = 0.30*** | r = 0.63*** | — |
| Age | r = −0.02 | r = −0.14* | r = −0.15 |
| Farming experience | r = −0.23*** | r = −0.28*** | r = −0.18** |
| Ruminant farming experience | r = −0.34*** | r = −0.27*** | r = −0.19** |
| Farm size | r = 0.17* | r = 0.24*** | r = −0.00 |
| Income from ruminant farming | r = 0.15* | r = 0.09 | r = 0.04 |
| Gender (male vs. female) | U = 4398.5 | U = 3608.0 | U = 3754.5 |
| Education (educated vs. uneducated) | U = 5300.0 | U = 5084.5 | U = 4930.5 |
| Veterinary services (available vs. unavailable) | U = 5227.0 | U = 5848.0 | U = 6616.0* |
| Type of ruminants (cattle vs. sheep/goats) | U = 3265.0*** | U = 3301.5*** | U = 4090.5* |

Values are Pearson correlation coefficients (r) for continuous variables and Mann–Whitney U statistics for categorical comparisons. * $p \le 0.05$, ** $p \le 0.01$, *** $p \le 0.001$.

These results indicate that more experienced farmers tended to perceive climate risks as less severe and reported lower adoption of both adaptation and mitigation practices, potentially reflecting reliance on traditional knowledge or perceptions of climate variability as routine. Farm size, in contrast, showed a positive association with the adaptation practices index ($r = 0.24$) and a smaller positive association with risk perception ($r = 0.17$), suggesting that larger operations may have greater capacity to implement management-based adjustments. Income from ruminant farming showed only weak positive associations with the indices ($r \leq 0.15$) (Table 7).

Group comparisons reinforced these patterns. No statistically significant differences in any of the three indices were observed across gender or education level ($p > 0.05$). Access to veterinary services did not significantly affect climate risk perception or adaptation behaviors but was significantly associated with mitigation practices ($U= 6616$, $p= 0.01$), with higher mitigation scores reported among farmers who had access to veterinary services. Ruminant type was a particularly strong differentiator; sheep and goat producers exhibited significantly higher climate risk perception ($p < 0.001$), higher adoption of adaptation practices ($p < 0.001$), and higher mitigation practice scores ($p= 0.03$) than cattle producers. This pattern reflects the heightened climatic sensitivity and management demands characteristic of small-ruminant production systems (Table 7).

## DISCUSSION

This study provides context-specific evidence on climate risk perception and the adoption of sustainable production practices among ruminant farmers in northern Jordan. The consistently high values of the three indices indicate that farmers are not passive observers of climate change; rather, they are actively responding through the implementation of a broad range of adaptation and mitigation strategies. This pattern is consistent with findings reported in other empirical studies, including Nwobodo *et al.* (2022), which similarly highlight farmers' proactive engagement in climate-responsive livestock management. In addition, our multi-governorate analysis extends earlier localized studies (e.g., Al-Barakeh *et al.*, 2024; Ata *et al.*, 2021) by comparing both small and large ruminant systems across northern Jordan. While previous studies have often emphasized farming experience as a facilitator of adaptation, our results instead reveal a negative association between years of experience and both climate risk perception and reported climate-responsive practices. Given the cross-sectional design of this study, these relationships should be interpreted as associations rather than causal effects. This suggests that long-term farmers may perceive climate variability as routine, which can limit uptake of newer climate-smart measures. Alternatively, this may reflect resistance to change or incremental adaptation that is not captured by the survey instruments; however, these mechanisms cannot be disentangled within the present study design. These findings indicate that broad awareness campaigns are insufficient; instead, targeted extension and veterinary support are needed, particularly for experienced farmers and cattle producers, who showed lower risk perception and adoption levels than sheep and goat farmers.

The strong perception of heat stress, feed and water shortages, pasture degradation, disease pressure, and rising feed costs underscores that farmers already experience climate change as a daily operational challenge. These perceived risks mirror pathways identified in global reviews, where climate change undermines livestock productivity through direct thermal stress and indirect impacts on feed, water, and health (Rojas-Downing *et al.*, 2017; Thornton *et al.*, 2009; Sejian, 2013). The comparatively lower recognition of impacts on growth rate, milk yield, and milk quality suggests a cognitive gap between environmental stressors and their downstream production consequences. Similar gaps have been documented among smallholders elsewhere, where farmers accurately perceive changing weather patterns but do not always connect them to subtle changes in performance indicators (Joy *et al.*, 2020; Karimi *et al.*, 2018). Strengthening this linkage through targeted extension and simple decision-support tools could help farmers more explicitly weigh the economic benefits of stronger adaptation and mitigation efforts. Lower agreement on productivity-related items may reflect differences in attribution, where farmers do not always directly connect production changes to climate variability. Because qualitative methods were not included in this study, future interview-based research could help better capture farmers' local perspectives and explanations.

The results show that farmers have widely adopted microclimate management, vaccination, use of locally adapted breeds, feed storage, and water provision practices that are central to climate-resilient livestock management (Henry *et al.*, 2012; de Boer *et al.*, 2011; Hoque *et al.*, 2022). These measures are relatively low-cost, rely on local resources and knowledge, and offer immediately visible benefits, which likely explains their popularity. The limited endorsement of high concentrate feeding should be interpreted cautiously, as the questionnaire did not explicitly capture farmers' reasons for non-adoption. In northern Jordan, as in many semi-arid systems, feed costs already represent a major component of production expenses, and high concentrate use may not be financially viable or culturally favored (Al-Barakeh *et al.*, 2024; Awad *et al*., 2024). Moreover, poorly managed concentrate feeding can increase the risk of metabolic disorders and undermine animal health. Rather than promoting "high-concentrate diets" per se, advisory services may be more effective if they focus on balanced ration formulation, improved forage quality, and efficient use of locally available by-products (Sejian, 2013; Haque, 2018).

Mitigation practices reported by farmers such as, manure management, tree planting, feed supplementation, and reduced stocking density; align with many of the mitigation options identified in global and regional assessments (Opio *et al*., 2013; Sejian *et al*., 2016; Zhang *et al*., 2017). These practices also provide co-benefits, such as improved animal welfare, disease control, and landscape rehabilitation, making them attractive from both adaptation and mitigation perspectives (Haque, 2018; Varijakshapanicker *et al*., 2019). Yet, the relatively low uptake of rotational grazing is striking, particularly given its potential to enhance rangeland resilience, soil carbon sequestration, and water-use efficiency (Henry *et al*., 2012; Pretty and Bharucha, 2014). Similar constraints on rotational grazing have been noted in other dryland systems, often linked to fragmented land tenure, weak enforcement of grazing rules, and insufficient infrastructure such as fencing and water points (Tessema *et al*., 2014; Awad *et al*., 2024). Overcoming these barriers will likely require collective action and policy support, not just individual farmer decisions, for instance, community-based rangeland management, targeted investment in water infrastructure, and incentive schemes for maintaining vegetative cover (Sawalhah *et al*., 2024).

The observed positive correlations among climate risk perception, adaptation practices, and mitigation practices indicate that these dimensions are closely linked; however, the direction of influence cannot be established. This pattern is consistent with behavioural frameworks such as the Theory of Planned Behavior, which emphasize perceived risk and self-efficacy as key drivers of action (Karimi *et al*., 2018; Nwobodo *et al*., 2022; Zhang *et al*., 2017), However, the present study does not test a mechanistic behavioral model, and inference should remain associative. The weaker relationship between risk perception and mitigation suggests that mitigation actions may be viewed as more collective or long-term in nature and therefore less directly linked to farmers' immediate risk assessments, highlighting the need for supportive policy instruments and market-based incentives to complement individual decision-making (Zhang *et al*., 2017; Calvosa *et al*., 2009).

Socio-economic and institutional factors further shaped farmers' responses. The negative association between farming experience and climate-related indices suggests that more experienced farmers may rely on historical coping strategies rather than adopting practices explicitly framed as climate responses, a pattern observed in other contexts (Malami and Tukur, 2017; Nwobodo *et al*., 2022). In contrast, larger farm size was associated with greater adoption of adaptation practices, reflecting stronger capacity to invest in infrastructure and management improvements (Knowler and Bradshaw, 2007; Pannell *et al*., 2006). Given the strong positive skewness in farm size and income in this study, associations involving these variables should be interpreted cautiously, as they may be influenced by a small number of large operations. Access to veterinary services significantly varies with mitigation practices, underscoring the role of veterinarians as trusted channels for promoting climate-smart livestock management (Varijakshapanicker *et al*., 2019). Higher index scores among sheep and goat farmers likely reflect the greater exposure of small-ruminant systems to rangeland degradation and climate variability in northern Jordan, as well as structural differences between extensive small-ruminant and more semi-intensive cattle production systems. These findings identify sheep and goat producers as a priority group for targeted climate-smart interventions (Al-Barakeh *et al*., 2024; Awad *et al*., 2024; Sejian, 2013).

## CONCLUSIONS

This study provides; context-specific evidence based on self-reported responses, that ruminant farmers in northern Jordan are highly aware of climate-related risks and are actively responding through the adoption of a range of sustainable production practices. The consistently high scores for climate risk perception, adaptation, and mitigation indicate that farmers are not passive in the face of climate change, but are already implementing practical measures related to housing, animal health, feed and water management, and manure handling.

The positive relationships between risk perception and both adaptation and mitigation highlight the importance of awareness as a correlate of climate-smart behavior, while the weaker link with mitigation suggests that some practices may require stronger institutional support. Differences across farm size, access to veterinary services, and livestock type further underline the role of resources and advisory services in shaping farmers' responses. In particular, sheep and goat producers demonstrated higher engagement with climate-responsive practices than cattle farmers, reflecting their greater exposure to climatic variability.

Overall, the findings emphasize the need to strengthen veterinary and extension services, improve access to targeted climate information, and address structural constraints, such as those limiting rotational grazing to enhance the resilience and sustainability of ruminant production systems in arid environments. This study offers a solid empirical basis to inform policy and extension strategies aimed at supporting climate-smart livestock management in Jordan and similar dryland regions.

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## NOVELTY STATEMENT

This study is among the first in arid Jordan to quantify ruminant farmers' climate risk perception alongside adaptation and mitigation practices using reliable composite indices, while identifying key socio-economic and institutional factors associated with climate-smart livestock management.

## AUTHOR'S CONTRIBUTION

MNS designed the study, supervised all research activities, interpreted the findings, and prepared the manuscript draft. MAA contributed to study design, field coordination, and manuscript development. MSA performed the statistical analysis and contributed to data interpretation. TMH conducted field data collection and questionnaire administration. FAA and MRE critically reviewed the manuscript and contributed to scientific revision. All authors reviewed and approved the final manuscript.

### Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

### Conflict of interest

The authors have declared no conflict of interest.

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