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Prioritization of Risk Management Strategies for Dairy Cattle Farms in Semi-Arid Regions Using BWM–EDAS

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Abstract

Industrial dairy farms in semi-arid regions face multiple risks, including water scarcity, feed price volatility, animal diseases, and institutional constraints, which can undermine production efficiency and economic sustainability. This study identifies and prioritizes risk management strategies for industrial dairy farms in Mashhad County, northeastern Iran, using a fuzzy multi-criteria decision-making framework. A total of 31 risk management strategies, grouped into five categories—operational management, animal health and biosecurity, financial resilience, environmental sustainability, and institutional adaptation—were assessed against three criteria: productivity improvement, long-term sustainability, and profitability. The fuzzy Best–Worst Method (F-BWM) was used to determine criterion weights, while the fuzzy Evaluation based on Distance from Average Solution (fuzzy EDAS) was used to prioritize strategies based on judgments from 15 industrial dairy producers, veterinarians, and technical advisors. Criterion weights were relatively balanced (0.35, 0.34, and 0.31), indicating that no single criterion dominated the assessment. Professional consultancy ranked first, followed by implementation of a feed management program, monitoring feed quality and supply, diversification of genetic resources, and regular health monitoring. These findings underscore the importance of specialized expertise, feed management and quality control, genetic diversification, and preventive animal health management in strengthening farm-level risk management. In contrast, financial, environmental, and institutional strategies generally received lower priorities, which may reflect differences in perceived urgency, accessibility, and implementation constraints. Overall, strengthening farm-level technical and managerial capacity while improving the accessibility and credibility of supporting financial, environmental, and institutional mechanisms could enhance risk management and long-term sustainability in semi-arid dairy farming.

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1. Introduction

The livestock sector is an important component of agricultural economies, contributing to economic development, employment generation, rural livelihoods, and the functioning of interconnected value chains (Khade *et al.,* 2021; Pawlak and Kołodziejczak, 2019). In addition to supplying animal-source foods, livestock production supports a broad network of activities including feed supply, veterinary services, processing, and trade. As demand for animal products continues to increase with population growth, urbanization, and dietary change, improving the sustainability and capacity of livestock systems to cope with emerging risks has become an important policy and research priority (Smith *et al.,* 2019; Laibuni and Kirui, 2018). Sustainability in livestock production encompasses interrelated environmental, economic, and social dimensions, including resource use and environmental impacts, economic viability, and social conditions (Lebacq et al., 2013). Recent research also indicates a growing scientific focus on sustainability in dairy farming, reflecting the increasing importance of these dimensions in livestock systems (Serin *et al.,* 2025).

Within this broader context, dairy cattle production is exposed to multiple and interconnected risks that can affect productivity, profitability, and long-term farm sustainability (Jokhio *et al.,* 2016). These risks arise from animal diseases, climate variability, water scarcity, market fluctuations, feed shortages, institutional constraints, regulatory changes, and managerial deficiencies. Feed supply problems, in particular, can intensify production and financial pressures, while animal-health and market risks may interact and produce broader effects on farm performance (Chand *et al.,* 2023; Khan *et al.,* 2023). Such interdependencies mean that disturbances in one area can propagate across others; for example, disease outbreaks may increase production costs and reduce profitability, whereas climate-related feed shortages may intensify financial pressure and exposure to market volatility (Lakhani et al., 2023). Effective dairy-farm risk management therefore requires an integrated perspective that considers multiple sources of risk simultaneously rather than treating them as isolated problems (Cabrera, 2018; Kumar and Singh, 2021; Jokhio *et al.,* 2016).

These challenges become more pronounced in semi-arid regions, where water scarcity, recurrent droughts, and land degradation interact with economic and institutional constraints to increase production uncertainty (Hashemi and Azizi, 2018). Limited water availability can affect both direct livestock water requirements and the production and availability of feed, while climatic stress can amplify existing operational and financial risks. In such environments, the interaction among environmental, biological, economic, and institutional pressures increases the need for risk-management strategies that are both effective and applicable under resource constraints (Jubaedah *et al.,* 2024).

Against this background, Iran's livestock sector faces a distinctive combination of global and domestic pressures. Chronic water scarcity, exacerbated by prolonged droughts and overexploitation of aquifers, has placed severe constraints on agricultural production, including livestock systems that depend heavily on water for both animals and feed crops. This biophysical stress is compounded by macroeconomic instability, which erodes purchasing power and financial liquidity, and by the sector's reliance on imported feed, veterinary inputs, and technology. Fragmented institutional governance and the lack of coherent, coordinated policies further limit adaptive capacity and hinder the effective implementation of risk management strategies (Riahi and Seyyadati, 2023). Despite substantial growth in livestock output, structural inefficiencies remain pervasive in Iran's livestock sector (Mirzaie *et al.*, 2023; Shokohi *et al.*, 2019).

Within this national context, Mashhad County represents an important setting for examining risk management in industrial dairy farming. The county produces approximately 145,686 tons of milk annually and includes 87,472 purebred and 53,231 crossbred cattle, highlighting the scale and economic significance of dairy production in the region (Mollaei Jaghargh *et al.,* 2026). At the same time, industrial dairy farms in Mashhad operate under conditions characterized by groundwater over-extraction, rising feed and veterinary costs, climatic pressures, and exposure to animal-health risks. The county's proximity to international borders may further increase exposure to transboundary disease risks. These pressures are compounded by governance and coordination challenges that can create inconsistencies in the implementation of risk-management measures. Taken together, these conditions make Mashhad a relevant case for examining how alternative risk-management strategies can be evaluated and prioritized under semi-arid production conditions (Alizadeh *et al.,* 2020; Rahmati *et al.,* 2022).

Growing concerns regarding the resilience of livestock systems have led to an expanding body of research on livestock risk assessment and management. Early studies primarily focused on identifying major sources of risk affecting livestock enterprises. For instance, Jokhio *et al.* (2016) examined risk perceptions among livestock farmers and reported that disease outbreaks, feed shortages, and market fluctuations were among the most significant threats to farm sustainability. Similarly, Chand *et al.* (2023), based on a survey of 913 livestock farmers in India, identified animal health, genetic, market, and policy-related risks as the dominant sources of vulnerability and demonstrated that farmers' coping strategies varied significantly according to socio-economic characteristics. Extending this line of inquiry, Khan *et al.* (2023) applied a multi-criteria decision-making framework to assess risks within livestock supply chains and identified feed supply disruptions, animal diseases, and market uncertainties as the most critical sources of vulnerability affecting livestock enterprises.

Several studies have investigated biological and biosecurity-related risks in livestock production systems. Harun *et al.* (2022) assessed biosecurity conditions in dairy farms and concluded that inadequate implementation of biosecurity protocols significantly increased disease vulnerability. More recently, Zanon *et al.* (2024) analyzed data from 2,291 mountain dairy farms across Europe and found that biosecurity practices were strongly associated with animal welfare, milk quality, and economic performance. Likewise, Bushra *et al.* (2024) examined biosecurity, health, and disease-management practices among dairy farms in Bangladesh and reported that managerial characteristics and farm size significantly influenced risk-management performance. Ferreira *et al.* (2024) further demonstrated that dairy farms in southern Brazil exhibited distinct biosecurity profiles, suggesting that risk-management requirements differ considerably across production systems. Similarly, Lima-Campêlo *et al.* (2024), based on an assessment of 3,825 dairy farms in Québec, Canada, revealed considerable variation in the adoption of biosecurity measures, indicating persistent vulnerabilities to emerging animal-health threats and highlighting the need for improved preventive risk-management practices.

Other scholars have focused on economic and market-related risks affecting livestock enterprises. Hayran and Gül (2015), based on a survey of 96 dairy farmers in Adana, Türkiye, identified variability in feed prices as the most important source of perceived risk and disease prevention as a key risk-management strategy. Moradi *et al.* (2021) combined Monte Carlo simulation and Value-at-Risk techniques to evaluate the economic consequences of feed-price volatility and demonstrated the substantial financial exposure of livestock farms to market fluctuations. McKendree *et al.* (2021) investigated risk perceptions among cattle feedlot operators and found that output-price uncertainty and animal-health risks were the most influential factors affecting managerial decisions. Kołoszycz *et al.* (2024) showed that resilience in dairy farming systems is shaped by the combined effects of environmental conditions, economic performance, social capital, and institutional support, emphasizing the multidimensional nature of livestock sustainability. Similarly, Çevrimli *et al.* (2025) examined cattle enterprises in Türkiye from the perspective of animal-life insurance and developed an enterprise scoring system to support the assessment of insurance premiums and compensation payments. These findings collectively emphasize the need to consider economic, biological, environmental, and institutional dimensions when addressing risk and resilience in livestock production systems.

Similarly, recent studies on dairy farm resilience have emphasized that economic sustainability depends on the interaction of environmental, managerial, institutional, and market-related factors rather than on single risk categories alone. For example, Kołoszycz *et al.* (2024) showed that resilience in dairy farming systems is shaped by the combined effects of environmental conditions, economic performance, social capital, and institutional support, emphasizing the multidimensional nature of livestock sustainability. These findings collectively suggest that effective livestock risk management requires integrated approaches that simultaneously address biological, economic, environmental, and institutional challenges. While this body of literature has substantially deepened understanding of risk in livestock systems, it also highlights the increasing complexity of managing interrelated biological, economic, environmental, and institutional risks. This complexity has motivated the need for structured decision-support approaches capable of translating heterogeneous risk information into actionable management priorities.

Nevertheless, important gaps remain, particularly with respect to industrial dairy farms in semi-arid environments. First, many existing studies focus on individual risk dimensions, such as price volatility, biosecurity, or climate shocks, or on specific farm types, and often treat biophysical, economic, and institutional risks in isolation. This limits their ability to capture how different sources of risk interact and accumulate at the level of industrial farms. Second, there is comparatively less research that translates complex risk landscapes into prioritized, context-specific sets of risk management strategies for industrial dairy farming systems, especially in middle-income, water-stressed settings. Third, existing approaches often focus on individual risk dimensions or rely on descriptive assessments that do not systematically rank alternative management strategies under uncertainty. These limitations indicate that risk management in industrial dairy farming should be conceptualized as a multi-criteria decision problem under uncertainty, where interdependent risk dimensions and competing objectives must be evaluated in an integrated manner rather than in isolation.

To address these gaps, this study prioritizes risk management strategies for industrial dairy farms in Mashhad County, north-eastern Iran. The study focuses on identifying the strategies that warrant greater attention in managing the risks faced by industrial dairy farms and on providing evidence to support their prioritization under local production conditions. By linking identified risks with practical management responses, the study contributes context-specific evidence to the literature on dairy farm risk management and provides a basis for more targeted managerial and policy decisions. Overall, the study provides practical insights for veterinarians, advisors, farm managers, and policymakers aiming to improve risk governance, strengthen herd health management, and enhance the sustainability of industrial dairy farming systems under uncertainty.

2. Materials and methods

2.1 Research Design

Selecting appropriate risk management strategies for industrial livestock farms is a complex multi-criteria decision problem because strategy performance cannot be adequately evaluated from a single perspective. Decisions must simultaneously incorporate technical efficiency, economic feasibility, and long-term sustainability under conditions of uncertainty and subjective expert judgment. Therefore, traditional single-criterion or purely descriptive approaches are insufficient for supporting robust decision-making in such environments. To address this complexity, the study adopted an integrated fuzzy multi-criteria decision-making (MCDM) framework that combines expert knowledge with structured quantitative analysis to identify, evaluate, and prioritize risk management strategies for industrial livestock farms in semi-arid regions.

The research design followed a sequential four-stage procedure (Fig 1). First, a comprehensive literature review was conducted across studies related to livestock risk management, agricultural resilience, and sustainability to extract an initial pool of potential strategies. Second, this list was refined through a structured expert validation process. The preliminary strategies were reviewed for conceptual overlap, clarity of wording, and applicability to industrial livestock systems in the study area. Strategies with distinct management scopes were retained as separate alternatives, while ambiguously worded strategies were revised to clarify their intended management action. The final strategy pool was established after this structured screening and expert validation process, resulting in 31 distinct risk management strategies that were considered relevant and applicable to industrial dairy farming in the study area. Third, the importance of evaluation criteria was determined using the Fuzzy Best–Worst Method (F-BWM). This method was particularly suitable for expert-based decision problems because it reduced the number of pairwise comparisons while improving consistency in weight estimation under uncertainty. Compared with Fuzzy AHP, Fuzzy BWM requires substantially fewer pairwise comparisons while retaining the ability to incorporate uncertainty in expert judgments through fuzzy numbers, thereby reducing respondent burden and the potential for inconsistency. Fourth, the prioritization of strategies was carried out using the Fuzzy Evaluation based on Distance from Average Solution (F-EDAS), which ranked alternatives based on their relative distances from an average solution while incorporating uncertainty in linguistic expert judgments.

Figure 1. Research process adopted in this study for prioritizing risk-management strategies in industrial dairy farms.

The integration of F-BWM and F-EDAS formed a coherent decision-support structure in which reliable criteria weighting and robust alternative ranking were achieved within a unified fuzzy environment. In this framework, F-BWM captured the relative importance of decision criteria, while F-EDAS translated these weighted criteria into a stable and discrimination-sensitive ranking of risk management strategies.

2.2 Study Area

Mashhad County, located in Razavi Khorasan Province in northeastern Iran, is an important center of dairy cattle production within the province. According to the Agricultural Jihad Organization of Razavi Khorasan Province (2023), the county produces approximately 145,686 tons of milk annually, accounting for about 15.3% of the province's total milk production, and has 87,472 purebred and 53,231 crossbred cattle. Industrial dairy farms in the county operate under semi-arid conditions, with production shaped by variation in herd structure and feed availability, dependence on groundwater resources, and exposure to climatic fluctuations. These conditions interact with input-market, animal-health, financial, and managerial factors at the farm level, forming a multifaceted operating environment for risk management in industrial dairy farming (Mollaei Jaghargh *et al.,* 2026). The location of Mashhad County within Razavi Khorasan Province is shown in Fig 2.

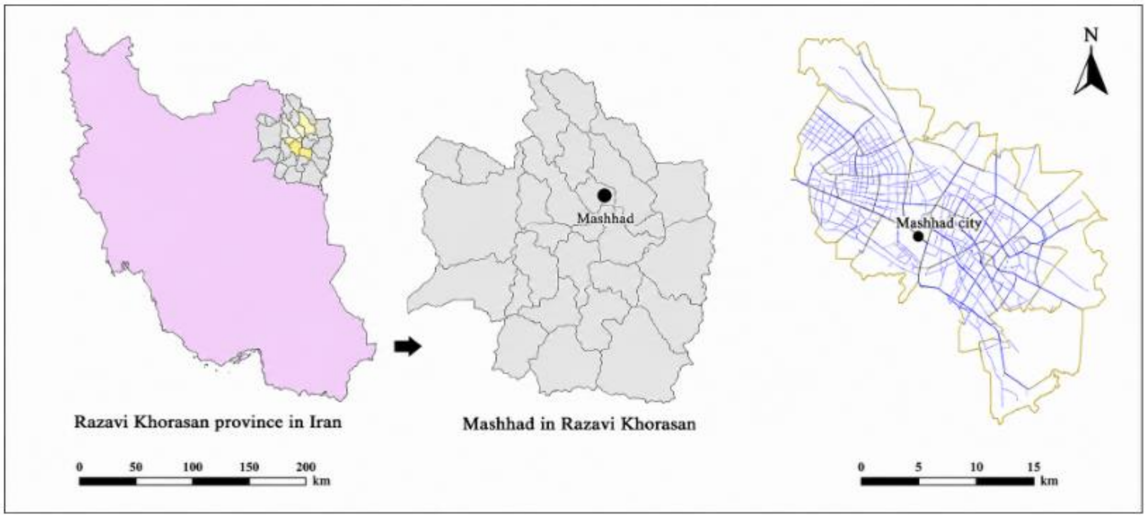

Figure 2. The geographical location of the study area in Razavi Khorasan province, Iran (Firoozzare *et al.,* 2023).

2.3 Data Collection

Data were collected in 2024 through a structured questionnaire administered to a purposively selected panel of 15 experts using expert sampling, with relevant and complementary expertise in industrial dairy farming and livestock risk management under semi-arid conditions. The panel comprised industrial livestock producers with at least 10 years of managerial experience, practicing veterinarians specializing in large-animal production, and technical advisors or senior staff from public and private organizations engaged in livestock extension, animal health, and feed and input supply in Mashhad County (Table 1). Similar expert-panel sizes have been used in previous MCDM applications; for example, Moktadir *et al.* (2026) employed 15 experienced experts in a BWM–fuzzy-TOPSIS framework, while Krisciukaitiene and Bathaei (2025) involved 15 senior managers in a BWM application for the dairy sector.

Table 1. Demographic characteristics of the expert panel (N= 15).

Characteristic	Category	n (%)
Gender	Male	11 (73.3)
	Female	4 (26.7)
Age	Years 40 ≥	4 (26.7)
	Years 41-55	6 (40.0)
	Years 55 <	5 (33.3)
Educational level	Bachelor's degree	5 (33.3)
	Master's degree	6 (40.0)
	Doctoral degree	4 (26.7)
Professional experience	years 6–10	5 (33.3)
	years 11–20	3 (20.0)
	years 21–30	6 (40.0)
	years 30 <	1 (6.7)

The questionnaire consisted of two main sections. In the first section, experts assessed the relative importance of the three evaluation criteria, namely productivity improvement, long-term sustainability of livestock units, and profitability, using the Fuzzy Best–Worst Method (F-BWM). For the BWM comparisons, experts employed a three-level linguistic importance scale comprising "equally important," "weakly important," and "fairly important" to indicate the relative importance of the best criterion compared with the remaining criteria and of each criterion compared with the worst criterion. Experts recorded their assessments by selecting the corresponding predefined linguistic category in the questionnaire, rather than entering numerical values directly. The resulting linguistic assessments were subsequently represented by triangular fuzzy numbers (TFNs). In the second section, experts evaluated the performance of each of the 31 identified risk management strategies with respect to each criterion. For the F-EDAS assessment, a separate five-point linguistic scale ranging from "very low" to "very high" was used to assess the perceived effectiveness of each strategy under local conditions. For each item, experts selected the appropriate predefined linguistic category by marking the corresponding option in the questionnaire; numerical values were not entered directly by the respondents. Before the main survey, the questionnaire was pre-tested with two experts to assess item clarity and consistency of the linguistic scales, and minor wording adjustments were made accordingly. Most interviews were conducted face-to-face at the experts' workplaces, with additional responses obtained through online consultation when in-person participation was not feasible.

2.2. Methodological Framework

The methodological framework establishes the analytical structure used to prioritize risk management strategies for industrial dairy farms. It links the decision goal, evaluation criteria, alternative strategies, and expert assessments within a unified fuzzy multi-criteria decision-making structure. The decision goal is to prioritize alternative strategies according to their expected contribution to key dimensions of dairy farm performance. The evaluation criteria comprise productivity enhancement, sustainability of dairy operations, and profitability improvement, while the alternatives consist of 31 risk management strategies organized into five categories: operational management, animal health and biosecurity, financial resilience, environmental sustainability, and institutional adaptation.

The assessment draws on the judgments of 15 domain experts, including industrial dairy producers, veterinarians, and technical advisors. Their evaluations were expressed using linguistic terms represented by triangular fuzzy numbers (TFNs), allowing uncertainty and imprecision in expert assessments to be incorporated into the decision process. The Fuzzy Best–Worst Method (Fuzzy BWM) was used to derive the relative weights of the evaluation criteria, whereas the Fuzzy Evaluation based on Distance from Average Solution (Fuzzy EDAS) was used to rank the risk management strategies. Together, these methods provide a structured and reproducible basis for comparing alternative strategies under linguistic uncertainty (Guo and Zhao, 2017; Schitea *et al.,* 2023).

2.2.1. Fuzzy Best–Worst Method (Fuzzy BWM)

The relative importance of the evaluation criteria was determined using the Fuzzy Best–Worst Method (Fuzzy BWM). In this approach, experts first identified the best (most important) and worst (least important) criteria. Subsequently, pairwise comparisons were elicited between the best criterion and all other criteria as well as between each criterion and the worst criterion using linguistic expressions represented by triangular fuzzy numbers. These judgments are expressed using triangular fuzzy numbers $\tilde{a}(l, m, u)$, generating two fuzzy comparison vectors (Heidary-Dahooie *et al.,* 2022; Azadnia *et al.,* 2021; Ecer and Pamucar, 2020; Brunelli and Rezaei, 2019):

- Best-to-Others vector:

$$\tilde{B}^A = (\tilde{a}_{B1}, \tilde{a}_{B2}, \dots, \tilde{a}_{Bn}) \quad (1)$$

Where n denotes the total number of evaluation criteria included in the decision framework. In the present study, the evaluation framework comprised three criteria.

- Others-to-worst vector:

$$\widetilde{W}^{A} = (\tilde{a}_{1W}, \tilde{a}_{2W}, \dots, \tilde{a}_{nW}) \tag{2}$$

The fuzzy weights $\widetilde{w}_j(l_j, m_j, u_j)$ are obtained by solving the following optimization model that minimizes the maximum deviation ξ between the derived weights and the fuzzy comparison values (Abedi and Shahbaz-Zadeh, 2025; Mi and Liao, 2019):

(1) Optimization model

$\min\ \xi$

subject to:

$$\left| \frac{\widetilde{w}_B}{\widetilde{w}_j} - \tilde{a}_{Bj} \right| \leq \xi$$

$$\left| \frac{\widetilde{w}_j}{\widetilde{w}_W} - \tilde{a}_{jW} \right| \leq \xi \tag{3}$$

All arithmetic operations involving triangular fuzzy numbers (TFNs), including the division and subtraction operations in Eq. (3), were performed according to standard TFN arithmetic rules rather than by treating the fuzzy quantities as crisp values. The optimal inconsistency value (ξ) was obtained from the optimization model, with smaller values indicating greater consistency among the expert judgments (Amiri et al., 2021). Following Guo and Zhao (2017), the consistency ratio (CR) was calculated for each expert as $CR=\xi*/CI$, where the consistency index (CI) was determined according to the best-to-worst comparison value. A CR value of 0.10 or lower was considered acceptable. The resulting fuzzy weights were then defuzzified (e.g., using the centroid method) and normalized so that $\sum_{j=1}^{n} w_j = 1$.

2.2.2. Fuzzy EDAS Method

Following the derivation of fuzzy weights, the 31 risk response strategies were prioritized using the fuzzy Evaluation based on Distance from Average Solution (fuzzy EDAS). First, a fuzzy performance matrix is constructed as:

$$\tilde{X} = [\tilde{x}_{ij}] \tag{4}$$

where each fuzzy value $\tilde{x}_{ij}(l_{ij}, m_{ij}, u_{ij})$ denotes the assessed performance of strategy $i$under criterion j. The fuzzy average for each criterion is computed using:

$$\tilde{x}_j = \frac{1}{m}\sum_{i=1}^{m} \tilde{x}_{ij} \tag{5}$$

where (m) denotes the total number of alternatives (risk response strategies), which is 31 in the present study. Because $\tilde{x}_{ij}$ and $\tilde{x}_j$ are triangular fuzzy numbers, they were first converted into comparable crisp representations using the Graded Mean Integration Representation (GMIR). Let $\tilde{x}_{ij}{}^*$and $\tilde{x}_j{}^*$ denote the resulting crisp representations of $\tilde{x}_{ij}$ and $\tilde{x}_j$, respectively. The positive and negative distances of each strategy from the average solution were then calculated as (Maleki and Pazhnegi, 2024):

$$PD_{ij} = \max(0, x_{ij}{}^* - x_j{}^*), ND_{ij} = \max(0, x_j{}^* - x_{ij}{}^*)$$

(6)

The resulting signed differences were used to distinguish positive and negative deviations from the average solution, with negative values set to zero. This procedure provides a consistent crisp basis for calculating the positive and negative distances (Abbasi *et al.,* 2016; Ilieva, 2018). Next, the weighted sums of PD and ND are obtained using the defuzzified and normalized BWM weights (Rehman, 2025):

$$SPD_i = \sum_{j=1}^{n} \widetilde{w}_j \cdot PD_{ij}, \qquad SND_i = \sum_{j=1}^{n} \widetilde{w}_j \cdot ND_{ij} \tag{7}$$

To ensure comparability across strategies, normalization is performed as follows (Zeng *et al.,* 2023):

$$N_{SPD_i} = \frac{SPD_i}{\max(SPD)}, \qquad N\_SND_i = 1 - \frac{SND_i}{\max(SND)} \tag{8}$$

The complementary form used for N_SPD_i converts the negative distance into a benefit-oriented measure, such that a smaller negative distance results in a higher normalized score. This is consistent with the logic of the EDAS method, in which alternatives with lower negative distances receive higher normalized scores (Zeng *et al.,* 2023). Finally, the overall appraisal score for each strategy is calculated (Nouran et al., 2021):

$$AS_i = \frac{1}{2}(N\_SPD_i + N\_SND_i) \tag{9}$$

All optimization procedures for the Fuzzy BWM were implemented in Python using the PuLP optimization library, whereas the Fuzzy EDAS calculations were performed in Microsoft Excel 365 using custom fuzzy logic functions. Despite the use of different computational environments, both procedures were implemented directly from the mathematical formulations and fuzzy arithmetic rules specified above, with identical defuzzification and normalization principles applied throughout the analysis. Accordingly, the software environment served only as the computational platform and did not affect the underlying MCDM formulation or decision rules. The complete mathematical specifications and computational steps are reported to facilitate independent reproduction of the analysis.

3. Results and Discussion

To assess the consistency of the expert judgments, the consistency ratio (CR) was calculated following Guo and Zhao (2017). The highest CR among the 15 experts was 0.084, which was below the 0.10 threshold, indicating an acceptable level of consistency in the pairwise comparisons. Estimation of the criteria weights using the fuzzy BWM shows that the three evaluation criteria are of broadly comparable importance (Table 2). Productivity enhancement received the highest weight (0.35), followed by long-term sustainability of livestock units (0.34) and profitability (0.31). The narrow spread among these weights indicates that experts viewed productivity, sustainability, and profitability as closely interrelated dimensions of risk management rather than as competing objectives. Thus, although productivity emerged as the leading priority, the relatively similar weights assigned to sustainability and profitability suggest that effective risk management in industrial dairy farms requires simultaneous attention to production efficiency, long-term farm viability, and economic performance. This prioritization is consistent with the conditions faced by industrial livestock producers in Mashhad, who operate under rising input costs, recurrent droughts, and increased exposure to climate-related stresses such as extended heatwaves and chronic water shortages. Taken together, the narrow spread of the weights suggests that risk-management strategies should simultaneously address productivity, sustainability, and profitability rather than rely on a single dominant objective or a trade-off among these dimensions. Similar to this study, Streimikis *et al*. (2024) also found that the assessment of agricultural sustainability requires consideration of multiple economic, environmental, and social dimensions rather than a single dominant objective. This broader multidimensional perspective is consistent with the relatively balanced weighting observed in the present study.

Table 2. Weights and Ranking of Evaluation Criteria Using Fuzzy BWM.

Criterion	Code	Weight	Rank
Productivity Enhancement	C2	0.35	1
Sustainability of Livestock Unit	C3	0.34	2
Profitability Increase	C1	0.31	3

After determining the criteria weights, the 31 key risk response strategies (Table 3) were evaluated using the fuzzy EDAS method. The highest-ranked strategy was A25, use of professional consultancy, with an appraisal score of 1.000. This finding suggests that experts attached particular importance to access to specialized knowledge and professional support in managing the multidimensional risks faced by industrial dairy farms. Professional consultancy may help farm managers integrate technical knowledge related to nutrition, animal health, reproduction, input procurement, and market conditions into farm-level decision-making. The second highest-ranked strategy was A7, implementation of a feed management program, with an appraisal score of 0.974, followed by A6, monitoring feed quality and supply, with a score of 0.963. The high ranking of these two feed-related strategies indicates that feed management and feed-quality control were perceived as important and relatively controllable dimensions of risk reduction. Together with professional consultancy, these results suggest a preference for interventions that combine specialized knowledge with direct management of key production inputs. The prominence of feed-related strategies is broadly consistent with evidence from other dairy-production contexts. Hayran and Gül (2015), based on 96 dairy farmers in Adana, Türkiye, identified variability in feed prices as the most important perceived source of risk and disease prevention as the most important risk-management strategy. Although the specific ordering differs from the present study, their findings are broadly consistent with ours in highlighting feed-related risks and preventive management as central components of dairy-farm risk management. Bellingeri *et al.* (2020) also showed that optimizing nutritional-resource allocation reduced whole-farm feed costs by an average of 7.8% and feed cost per 100 kg of milk by 6.7% in high-yielding dairy herds. This finding is consistent with the high priority assigned to A7 in the present study, although their analysis focused on nutritional-resource optimization rather than risk-management prioritization. Brito *et al.* (2021) similarly applied a multi-criteria risk-assessment framework to the livestock supply chain and identified input-supply risk as the most important risk dimension, with poor-quality and insufficient feed among the highest-priority risks. This finding is consistent with the present study, in which feed management (A7) and monitoring feed quality and supply (A6) ranked second and third, respectively.

In the context of Mashhad, where feed costs exceed 60% of total operational expenses, improvements in feed efficiency and feed-cost control could therefore have important implications for overall farm performance. Effective feed management can also contribute to improved metabolic status and animal health, while systematic monitoring of feed quality and storage is particularly relevant under semi-arid production conditions, where inadequate storage conditions may increase the risk of fungal growth and mycotoxin contamination. Sharafi *et al.* (2024), focusing specifically on Iran, emphasized the importance of continuous monitoring of animal-feed quality and storage conditions to mitigate aflatoxin M1 contamination in dairy products. This finding is consistent with the present study, in which A6 received the third-highest appraisal score. Kihal *et al.* (2023) provide complementary evidence by showing that feed-related interventions can reduce aflatoxin transfer into milk in dairy cows. Although their focus was specifically on aflatoxin mitigation rather than farm-level risk prioritization, their findings reinforce the importance of feed-quality control, consistent with the high ranking of A6 in the present study.

Table 3. Prioritization of Risk Response Strategies Using Fuzzy EDAS.

Category	Risk Response Strategies	Code	Rank	Appraisal Score
Operational Management	Implementation of a feed management program	A7	2	0.974
	Monitoring feed quality and supply	A6	3	0.963
	Diversification of genetic resources	A9	4	0.922
	Use of precision agricultural technologies	A5	7	0.717
	Accurate record keeping	A10	12	0.582
	Staff training	A17	13	0.568
	Investment in quality infrastructure	A13	14	0.557
Animal Health and Biosecurity	Regular health monitoring	A3	5	0.765
	Optimization of reproductive management	A11	6	0.749
	Maintaining a comprehensive vaccination program	A4	10	0.612
	Implementation of animal welfare standards	A19	11	0.589
	Implementation of biosecurity measures	A2	20	0.465
Financial Resilience	Market diversification	A20	15	0.492
	Market and economic analysis	A26	17	0.488
	Effective cash flow management	A22	18	0.481
	Conducting regular financial audits	A15	19	0.479
	Negotiation of fixed-price contracts	A16	21	0.448
	Income source diversification	A1	22	0.422
	Financial and budget management	A29	24	0.320
	Use of insurance coverage	A18	26	0.263
Environmental Sustainability	Monitoring environmental conditions	A24	8	0.639
	Ensuring adequate water supply	A8	9	0.629
	Effective waste management	A12	25	0.276
	Sustainability practices	A28	30	0.138
Institutional Adaptation	Use of professional consultancy	A25	1	1.000
	Regular updating and revision of farm policies	A21	16	0.492
	Development of emergency response plans	A14	23	0.375
	Leveraging cooperative resources	A23	27	0.253
	Emergency planning	A27	28	0.221
	Establishment and operation of a risk management unit	A31	29	0.138
	Compliance with regulations	A30	31	0.000

The fourth highest-ranked strategy was A9, diversification of genetic resources, with an appraisal score of 0.922. Following the strong emphasis on feed-related strategies, the high ranking of genetic diversification suggests that experts also viewed herd-level biological resilience as an important component of risk management. However, in intensive dairy systems, genetic diversification should not be interpreted as replacing specialized high-yield dairy breeds with indigenous breeds. Rather, it is more appropriately understood as structured cross-breeding programs that combine the productivity of specialized dairy genetics with locally adapted traits such as heat tolerance, disease resistance, and environmental robustness. This interpretation is broadly consistent with Vanvanhossou *et al.* (2021), who emphasized the importance of context-specific genetic improvement strategies that combine productivity with robustness to local stressors. Similarly, Brito *et al.* (2021) argued that sustainable dairy breeding should move beyond single-trait selection for milk yield and incorporate resilience-related traits. Thus, the relatively high ranking of A9 in the present study supports an approach that seeks to balance productive performance with adaptation to local environmental and biological stresses. The importance of herd resilience is further reflected in the next two highly ranked strategies. A3, regular health monitoring, ranked fifth with an appraisal score of 0.765, while A11, optimization of reproductive management, ranked sixth with a score of 0.749. These results indicate that experts also considered preventive animal-health management and reproductive efficiency important components of farm-level risk reduction. Regular health monitoring can facilitate earlier detection of disease and timely intervention, while effective reproductive management can reduce reproductive losses and support herd productivity and longevity. Ries *et al.* (2022) similarly reported that participation in veterinary herd-health programs was associated with higher milk yield and emphasized the value of preventive management, which is consistent with the relatively high priority of A3 in the present study. In addition, Giordano (2019) and Krpálková *et al.* (2020) reported positive economic effects of improved reproductive performance, supporting the relatively high ranking of A11.

Taken together, the concentration of high-ranking strategies in professional consultancy, feed management and feed-quality control, genetic diversification, animal health, and reproductive management suggests that experts tended to prioritize interventions that are relatively controllable at the farm level and can influence several dimensions of performance simultaneously. This pattern also indicates that risk management in industrial dairy farms may be most effective when these measures are implemented as complementary components of an integrated management approach rather than as isolated interventions.

While the highest-ranked strategies were predominantly farm-level and operational, financial risk-management strategies received relatively lower priorities. A18, use of insurance coverage, ranked 26th with an appraisal score of 0.263, while A23, leveraging cooperative resources, ranked 27th with a score of 0.253. Their relatively low positions may indicate that experts perceived existing financial and collective risk-management mechanisms as less accessible, reliable, or immediately useful than farm-level technical interventions. This interpretation should not, however, be taken to mean that insurance and cooperative mechanisms are inherently less valuable; rather, their practical contribution may depend strongly on institutional design and implementation conditions. Janowicz-Lomott and Łyskawa (2014), in their analysis of agricultural risk-management instruments in the European Union, highlighted the potential role of insurance and mutual funds in reducing agricultural risk and stabilizing farm income. Their findings therefore support the potential value of financial risk-management mechanisms, while also illustrating the importance of appropriate institutional arrangements for their effective implementation. This provides a complementary interpretation of the present finding: the relatively low ranking of A18 and A23 may reflect limitations in the way these mechanisms are currently perceived or implemented rather than their lack of risk-management potential. Evidence from Türkiye provides a more specific explanation for the insurance result. Çevrimli *et al.* (2025) developed and validated an objective enterprise-scoring scale for animal-life insurance and showed that more systematic and transparent enterprise assessment can improve the basis for premium determination and compensation. This finding is complementary to the present result because it suggests that strengthening the objectivity and transparency of insurance assessment could potentially improve confidence in livestock insurance and increase its practical usefulness. The relatively low priority assigned to these strategies is also consistent with evidence from Iran. Moradi *et al.* (2021) showed that profit risk in cattle-fattening enterprises is highly sensitive to fluctuations in the prices of major inputs such as calves, maize, and alfalfa, highlighting the importance of broader market stabilization alongside farm-level risk management. Similarly, Karami and Barani (2018) reported that institutional and credit-related constraints limit the effectiveness of financial support instruments for livestock producers. These findings are broadly consistent with the present study in suggesting that financial risk-management mechanisms cannot be considered independently of the wider market, institutional, and support environment.

Taken together, the results suggest that improving the practical role of insurance and cooperative mechanisms may require greater transparency, easier access, clearer benefit structures, and stronger institutional trust. Such improvements could help complement, rather than replace, the farm-level strategies that received the highest priorities in the present study. A28, sustainability practices, and A30, compliance with regulations, occupied the bottom of the ranking, with appraisal scores of 0.138 and 0.000, respectively. Their low positions suggest that experts assigned relatively less immediate priority to sustainability-oriented and regulatory measures than to strategies with more direct effects on production, herd health, and farm-level economic performance. This pattern may reflect the practical constraints faced by industrial dairy farms in a semi-arid environment, where producers must simultaneously cope with input-price volatility, water scarcity, climatic stress, and operational pressures. This finding does not necessarily imply that sustainability and regulatory compliance are considered unimportant. Rather, it may indicate a difference between the timing of perceived benefits and the immediate priorities of farm managers. Ramírez-Gómez *et al.* (2025) showed that sustainable livestock practices can generate longer-term benefits for environmental resilience, productivity, and social acceptability. Their findings therefore provide a complementary perspective to the present results: while sustainability practices may have substantial long-term value, their relatively low priority in the current ranking may reflect the difficulty of translating those longer-term benefits into immediate farm-level incentives. A similar interpretation applies to regulatory compliance. Compliance measures may entail additional administrative, technical, or financial requirements, while some of their benefits are realized over longer time horizons. In the context of the present study, the lowest score assigned to A30 may therefore reflect the perceived immediacy and controllability of alternative strategies rather than a rejection of environmental or regulatory objectives.

From a policy perspective, these findings suggest that sustainability and regulatory measures may be more effectively promoted when they are linked to tangible economic or risk-management benefits. For example, insurance premiums or other financial incentives could be linked to verified adoption of feed-management, animal-health, water-efficiency, or environmental practices, while tax incentives or targeted financial support could be used to encourage compliance with relevant environmental standards. Such mechanisms may help align short-term farm-level economic priorities with longer-term sustainability and regulatory objectives.

4. Conclusions

This study developed and applied a fuzzy BWM–EDAS framework to prioritize risk management strategies for industrial dairy farms in Mashhad County, north-eastern Iran—a semi-arid setting characterized by chronic water scarcity and pronounced volatility in input prices. The relatively balanced weighting of criteria suggests that experts assess risk management through a combined lens of herd productivity, farm continuity and long-term sustainability, and economic viability, rather than treating risk as a purely financial issue. The highest-ranked strategies were operational and herd-level actions, particularly professional consultancy, structured feed management, feed-quality monitoring, genetic/resource diversification, routine animal health surveillance, and improved reproductive management. These measures were prioritized because they directly support animal performance, reduce preventable losses, and remain largely within the control of farm managers, enabling timely responses to climatic stress and market shocks. In contrast, formal financial and institutional instruments, such as insurance and cooperative participation, received lower priority. This pattern may reflect concerns regarding administrative burden, limited transparency, and low confidence in formal risk-transfer and collective-action arrangements, suggesting that wider uptake of such instruments may depend on their accessibility, credibility, and alignment with producers' operational needs. From a risk-governance perspective, the findings also suggest that sustainability-oriented measures may be more effectively implemented when embedded within operational risk-reduction practices that producers already value. Based on the overall findings, the following policy recommendations are proposed:

- **Prioritize farm-level technical and herd-management interventions:** Greater emphasis should be placed on professional consultancy, structured feed management, feed-quality and supply monitoring, genetic/resource diversification, routine animal health monitoring, and reproductive management, as these strategies directly address production and herd-management risks.

- **Integrate sustainability into routine farm management:** Although sustainability received a high weight as an evaluation criterion, stand-alone sustainability practices received relatively low priority among the alternatives. Environmental objectives may therefore gain greater practical relevance when incorporated into established production and resource-management practices, including improved feed and water-use efficiency and reduced resource waste.
- **Strengthen preventive veterinary, advisory, and extension support:** Veterinary, advisory, and extension services should support continuous health surveillance, reproductive management, early risk detection, and the translation of technical knowledge into practical farm-level actions.
- **Improve the effectiveness of financial and institutional mechanisms:** The relatively low rankings of insurance coverage, cooperative resources, sustainability practices, and regulatory compliance indicate a need to improve the accessibility, credibility, and practical effectiveness of financial and institutional mechanisms and to align them more closely with the operating conditions and risk-management needs of industrial dairy farms.
- **Support risk-management capacity in larger dairy enterprises:** Although establishing a formal risk-management unit received relatively low priority, larger dairy enterprises could benefit from dedicated risk-management functions for structured risk identification, monitoring, and response. Improved access to market information and stronger coordination among dairy-sector actors could further support responses to input and market uncertainty.

The study is based on expert judgments from a single regional case in Mashhad County, which may limit the transferability of the findings to other dairy production systems and agro-ecological settings. In addition, the data were collected in 2024, and subsequent changes in feed prices, input costs, market conditions, climatic pressures, or institutional arrangements may have altered the relative salience of some risks over time. The findings should therefore be interpreted as reflecting the risk-management priorities perceived by relevant experts under the conditions prevailing during the study period rather than as static priorities over time. Expert-based assessments may also be influenced by individual experience, professional judgment, and local perceptions. Future research should therefore triangulate the fuzzy multi-criteria results with objective longitudinal farm-level evidence, including milk-yield records, animal-health indicators, and financial performance data, and assess the robustness of the strategy rankings across different dairy production systems, time periods, and agro-ecological settings. Further research could also examine the factors underlying the relatively lower prioritization of institutional and regulatory strategies and how these factors influence their adoption and implementation.

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اولویت‌بندی راهبردهای مدیریت ریسک در واحدهای صنعتی پرورش گاو شیری در مناطق نیمه‌خشک با استفاده از رویکرد BWM–EDAS

علی مولایی، علی فیروز زارع، نازنین یوسفیان، و امیرحسین عامری

چکیده

واحدهای صنعتی پرورش گاو شیری در مناطق نیمه‌خشک با مجموعه‌ای از ریسک‌ها، از جمله کمبود آب، نوسانات قیمت خوراک، بیماری‌های دامی و محدودیت‌های نهادی، مواجه هستند که می‌توانند بهره‌وری تولید و پایداری اقتصادی را تضعیف کنند. پژوهش حاضر با هدف شناسایی و اولویت‌بندی راهبردهای مدیریت ریسک در واحدهای صنعتی پرورش گاو شیری شهرستان مشهد، در شمال‌شرق ایران، با استفاده از یک چارچوب تصمیم‌گیری چندمعیاره فازی انجام شد. در این مطالعه، ۳۱ راهبرد مدیریت ریسک در پنج دسته شامل مدیریت عملیاتی، بهداشت و امنیت زیستی، تاب‌آوری مالی، پایداری زیست‌محیطی و سازگاری نهادی، بر اساس سه معیار بهبود بهره‌وری، پایداری بلندمدت و سودآوری ارزیابی شدند. روش بهترین–بدترین فازی (F-BWM) برای تعیین وزن نسبی معیارها و روش ارزیابی مبتنی بر فاصله از راه‌حل میانگین فازی (F-EDAS) برای اولویت‌بندی راهبردها، با استفاده از قضاوت‌های ۱۵ نفر از تولیدکنندگان گاو شیری صنعتی، دامپزشکان و مشاوران فنی، به کار گرفته شدند. وزن معیارها نسبتا متوازن بود (۰/۳۵، ۰/۳۴ و ۰/۳۱)، که نشان می‌دهد هیچ معیار واحدی بر ارزیابی‌ها غالب نبوده است. استفاده از مشاوره تخصصی بالاترین رتبه را کسب کرد و پس از آن اجرای برنامه مدیریت خوراک، پایش کیفیت و تأمین خوراک، تنوع‌بخشی منابع ژنتیکی و پایش منظم سلامت دام قرار گرفتند. این یافته‌ها بر اهمیت تخصص حرفه‌ای، مدیریت مؤثر خوراک و کنترل کیفیت، تنوع ژنتیکی و مدیریت پیشگیرانه سلامت دام در تقویت مدیریت ریسک در سطح واحد تأکید دارند. در مقابل، راهبردهای مرتبط با تاب‌آوری مالی، پایداری زیست‌محیطی و سازگاری نهادی، اولویت پایین‌تری دریافت کردند که می‌تواند بازتابی از فوریت ادراک‌شده، دسترسی و محدودیت‌های عملی اجرای آنها در شرایط کنونی باشد. در مجموع، یافته‌ها نشان می‌دهند که تقویت ظرفیت‌های فنی و مدیریتی در سطح واحد، همراه با بهبود دسترسی، اعتبار و طراحی سازوکارهای پشتیبان مالی، زیست‌محیطی و نهادی، می‌تواند به مدیریت مؤثرتر ریسک و پایداری بلندمدت در واحدهای صنعتی پرورش گاو شیری در مناطق نیمه‌خشک کمک کند.