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PARAMETERS FOR ASSESSING SHEEP WELFARE CONSIDERING MODERN APPROACHES IN THE CONTEXT OF ARTIFICIAL INTELLIGENCE AND PREDICTIVE ANALYTICS

Abstract

The article examines modern approaches to assessing sheep welfare using artificial intelligence (AI) and predictive analytics technologies. Traditional and innovative welfare assessment parameters are summarized, including behavioral, physiological, productive, and environmental indicators. The feasibility of integrating digital technologies, sensor systems, and machine learning algorithms to form an objective, continuous, and multifactorial assessment of animal status is substantiated. It has been established that the most promising approach is a multiparametric one that combines physiological, behavioral, environmental, and productive indicators. It is shown that the integration of Precision Livestock Farming (PLF) technologies, sensor systems, and machine learning algorithms enables continuous real-time monitoring and prediction of animal conditions. The need to develop digital AI-based models for sheep welfare assessment is justified.

Keywords: *sheep welfare, parameters, artificial intelligence, predictive analytics, precision livestock farming, One Health.*

Introduction. Modern sheep farming is developing under increasingly stringent requirements for ensuring animal welfare, which represents a key component of sustainable and ethically oriented livestock production. In the European Union and according to the recommendations of international organizations (FAO, WOA, EFSA), the concept of animal welfare has acquired a systematic character and includes the assessment of physiological status, behavioral responses, housing conditions, and the ability of animals to adapt to environmental changes.

Traditional approaches to sheep welfare assessment are mainly based on visual observation, periodic clinical examinations, and expert judgment, which limits their accuracy, objectivity, and timeliness. Therefore, there is a growing need to implement new technological solutions capable of providing continuous, automated, and multiparametric monitoring of animal condition.

Contemporary scientific research in sheep welfare assessment is characterized by a transition from subjective expert evaluations to objective, standardized, and digital monitoring systems based on animal-based measures (ABMs). This approach enables the assessment of the actual condition of the animal through physiological, behavioral, and clinical indicators, which are more informative compared to resource-based measures.

According to the scientific position of EFSA (European Food Safety Authority), the main welfare risks for sheep include heat stress, hunger, lameness, mastitis, and impaired adaptation. EFSA emphasizes that the most valid indicators are animal-based measures, in particular body condition score, locomotion score, and indicators of behavioral and physiological status, as well as productive and environmental parameters [1].

Of particular importance is the use of artificial intelligence (AI) and predictive analytics, which allow the integration of large datasets obtained from sensor systems, activity monitoring devices, GPS trackers, and computer vision technologies. This enables a shift from reactive to preventive and predictive welfare management, which is a key trend in the development of Precision Livestock Farming (PLF).

In the context of climate change, particularly increasing thermal stress and higher environmental temperature loads, the development of indicator systems reflecting the adaptive capacity of sheep becomes especially important. Such indicators include physiological (body temperature, heart rate, cortisol level), behavioral (locomotor activity, rumination, feed intake), and environmental (ambient temperature, humidity, temperature-humidity index (THI)) parameters.

Thus, the development of a parameter system for sheep welfare assessment considering modern approaches in the context of artificial intelligence and predictive analytics is a relevant scientific task with both theoretical and practical significance for the advancement of digital and climate-smart livestock production.

Review of recent research and publications. The current stage of sheep farming development is characterized by a transition from traditional methods of assessing productivity and animal welfare to digital monitoring technologies based on the concept of Precision Livestock Farming (PLF), sensor systems, and artificial intelligence algorithms. Recent scientific literature emphasizes that the integration of IoT solutions, computer vision, and machine learning models enables continuous, non-invasive monitoring of physiological status, behavior, and welfare levels of sheep in real time [2].

Particular attention is given by researchers to the development of welfare indicators based on animal-based measures (ABMs), including the assessment of behavior, lameness, body condition score, resting duration, and feeding activity. However, it has been established that some of these indicators require further validation regarding their reliability and repeatability under field conditions [3].

Within the European framework, a significant contribution has been made through the development of the Welfare Quality® system, which established the basis for a multi-criteria welfare assessment of animals based on four principles: good feeding, good housing, good health, and appropriate behavior. A further development

of this approach is the AWIN (Animal Welfare Indicators) project, specifically adapted for sheep and goats. The AWIN methodology includes validated indicators such as lameness, body condition score, fleece condition, dag score (soiling of the hindquarters), hoof lesions, and behavioral responses [3].

The modern stage of sheep farming development is also characterized by the increasing adoption of digital monitoring technologies based on Precision Livestock Farming (PLF), sensor systems, and artificial intelligence algorithms. Recent literature highlights that the integration of IoT solutions, computer vision, and machine learning models enables continuous, non-invasive monitoring of physiological status, behavior, and welfare levels of sheep in real time [4].

Current studies emphasize that the implementation of sensor technologies in sheep farming enables the automation of data collection related to animal behavior and physiological status. In particular, the use of accelerometers, GPS trackers, thermal sensors, and audio sensors provides continuous monitoring of locomotor activity, feed intake, rumination behavior, and heat stress [5].

A separate research direction involves the application of artificial intelligence (AI) and deep learning techniques for sheep behavior analysis. Scientific studies show that convolutional neural networks (CNNs) and YOLO models are used for behavior recognition, while computer vision systems are applied to movement assessment, and machine learning algorithms enable classification of states such as “rest – activity – stress.” Recent works also demonstrate the use of multimodal AI systems for behavior analysis without animal tagging, enabling real-time objective data acquisition.

Review studies confirm that the main AI applications in livestock production include animal detection, health assessment, behavioral classification, and early anomaly detection [4].

Despite significant progress, the current literature identifies several key challenges, including the lack of unified digital welfare models for sheep, limited integration of physiological and behavioral data, insufficient numbers of validated AI models for field conditions, and low standardization of sensor data across different housing systems. It is particularly emphasized that most Precision Livestock Farming (PLF) technologies are still at the experimental research stage and have not yet been fully implemented in commercial sheep farming [6].

Predictive analytics enables a shift from reactive to proactive herd management. The main application areas include heat stress prediction, early disease detection, productivity decline forecasting, and reproductive risk assessment.

Thus, an early warning system is being formed, which allows for the reduction of economic losses and improvement of animal welfare levels.

The conducted analysis demonstrates that research in the field of sheep welfare assessment is undergoing an intensive transformation driven by the transition from traditional observational methods to digital, sensor-based, and intelligent monitoring systems. The synthesis of leading research findings indicates that the primary driver of development is the integration of artificial intelligence technologies, IoT, computer vision, and predictive analytics, which collectively form the foundation of the modern Precision Livestock Farming (PLF) concept.

The purpose of the work is to determine and scientifically substantiate the parameters for assessing sheep welfare considering modern approaches in the context of artificial intelligence and predictive analytics. The study aims to develop an integrated system for monitoring physiological, behavioral, productive, and environmental indicators affecting animal welfare and adaptive capacity under modern livestock farming conditions.

Materials and methodology. The modern understanding of animal welfare is based on a comprehensive consideration of behavioral, physiological, productive, and environmental factors that are in constant dynamic interaction. In this context, there is a need to apply a multidisciplinary approach that integrates methods of animal science, veterinary medicine, bioengineering, information technologies, and mathematical modeling.

The analysis is based on a synthesis of contemporary scientific sources in the following areas:

- animal welfare science, particularly the conceptual frameworks of the Five Freedoms and Five Domains, which define the multidimensional nature of welfare assessment;

- precision livestock farming (PLF), which involves the use of digital technologies for continuous monitoring of individual animal status;

- application of artificial intelligence and machine learning for classification of behavioral patterns, analysis of physiological signals, and detection of anomalies in animal condition;

- use of computer vision for automatic behavior recognition, animal identification, and assessment of locomotor activity;

- development of IoT systems and sensor technologies in livestock production, enabling continuous data collection on physiological and environmental parameters;

- predictive analytics and time-series analysis, which allow modeling of animal condition dynamics and development of early warning systems for risk detection;

- modern approaches to assessing the impact of climatic factors (heat stress, Temperature-Humidity Index, THI) on sheep productivity and welfare.

An important element of the methodology is the transition from a descriptive to an analytical and predictive level of assessment, which enables not only the recording of the current welfare status but also the forecasting of potential risks of its deterioration. This creates prerequisites for the implementation of early warning systems and real-time decision-making in herd management.

Results and discussion. The research results in the field of sheep welfare assessment are formed at the intersection of animal science, veterinary medicine, bioengineering, and information technologies. A gradual transition is observed from descriptive approaches to quantitative digital models for assessing animal condition.

Scientific literature has established that sheep welfare is an integrated indicator shaped by behavioral responses, physiological status, housing conditions, productivity levels, and the adaptive capacity of the organism. The systematization of the main groups of indicators, methods of data collection, approaches to AI-based analysis, and

interpretation of results in the context of sheep welfare assessment are presented in Table 1.

Table 1

Parameters for Assessing Sheep Welfare Considering Modern Approaches

Group of indicators	Parameters	Methods of data collection	AI / analytical approaches	Interpretation (welfare relevance)
Behavioral indicators	Activity level, feeding behavior, rumination, social interactions, resting time	Video monitoring, accelerometers, audio sensors, human observation	Computer vision, machine learning classification, time-series clustering	Early and sensitive indicators of stress, discomfort, or adaptation status
Physiological indicators	Body temperature, heart rate, respiration rate, cortisol level	Wearable sensors, thermal sensors, biosensors, laboratory analysis	Predictive modeling, anomaly detection, regression models	Direct indicators of internal homeostasis and stress response
Productive indicators	Weight gain, growth rate, lactation	Zootechnical records	Machine learning predictive models	Efficiency of management and housing systems
Feeding behavior indicators	Feed intake, chewing time	RFID, smart feeders	anomaly detection	Appetite and metabolic status
Environmental indicators	Temperature, humidity, heat stress	IoT sensors	predictive analytics	Risks of heat/cold stress
Integrated index	Welfare Score	Integration of all data	AI dashboards, scoring models	Overall welfare level

Results from various studies demonstrate high variability of these indicators depending on genotype, housing technology, climatic conditions, feeding level, production management system, and the adaptive capacity of the organism to stress factors. It is particularly emphasized that in sheep farming even minor changes in housing conditions are rapidly reflected in animal behavior, physiology, and productivity.



It has been established that behavior is the most sensitive indicator of sheep welfare, namely: changes in locomotor activity serve as an early marker of stress; rumination duration decreases under heat stress and under deteriorating housing conditions; social isolation and reduced group interaction correlate with a decline in physiological status; and abnormal behavior (hypoactivity or hyperactivity) is an indicator of pathological conditions.

Generalized data show that the accuracy of behavior recognition using computer vision in modern studies reaches 85–95%, which significantly exceeds traditional visual observation methods.

The literature analysis indicates that body temperature is a basic indicator of heat stress; heart rate increases with elevated workload and stress; heart rate variability (HRV) is the most sensitive marker of adaptation, and a decrease in HRV consistently correlates with reduced productivity and deterioration of the overall animal condition; hormonal indicators (particularly cortisol) are used as a confirmatory marker of chronic stress.

Environmental conditions are a key external factor determining the level of sheep welfare. The Temperature-Humidity Index (THI) is the most widely used integrative indicator; when THI exceeds critical values, a reduction in feed intake and activity is observed; high ammonia concentration negatively affects the respiratory system; and the combination of high temperature and humidity has a synergistically negative effect. Most studies confirm a strong relationship between microclimate and the physiological state of animals. In sheep production, microclimatic conditions are critically important, especially during the housing (indoor) period. Lambs and high-producing ewes are particularly sensitive, as their adaptive capacity is limited. Across different sheep breeds, productivity differences between “comfortable” and “stressful” conditions may reach 15–30%.

The integrated index is the final summary indicator that combines all previous data blocks. The use of AI dashboards and scoring models enables the formation of a unified assessment of animal or flock status, classification of welfare levels (high, medium, low), and real-time decision-making.

The proposed system represents a modern multidimensional AI architecture for sheep welfare monitoring, combining behavioral signals as early indicators, physiological parameters as a medical basis, productive data as an economic criterion, feeding behavior as a metabolic marker, and environmental factors as external influences.

This integrated approach ensures a transition from reactive to proactive welfare management and fully complies with modern requirements of digital livestock farming and the One Health concept.

In summary, based on the scientific literature review, a SWOT analysis of sheep welfare assessment parameters was conducted considering modern artificial intelligence and predictive analytics approaches. It includes a comprehensive evaluation of the strengths and weaknesses of existing monitoring methods, as well as identification of potential opportunities and risks associated with further digitalization and integration into intelligent livestock management systems. The strengths and

weaknesses of behavioral, physiological, and environmental indicators were systematically analyzed, and key opportunities for their digital integration, as well as potential threats to the implementation of intelligent monitoring systems, were identified (Table 2).

Table 2

SWOT Analysis of Sheep Welfare assessment parameters

S - Strengths	W -Weaknesses
<ul style="list-style-type: none"> • Comprehensive nature of parameters: integration of behavioral, physiological, and environmental indicators • Possibility of objective measurement using sensors, video analysis, and biosensors • High informational value of parameters for assessing stress and health status • Early detection of behavioral deviations (feed intake, activity, social interaction) • Physiological markers (heart rate, body temperature, hormonal status) increase diagnostic accuracy • Environmental parameters (microclimate, stocking density) enable evaluation of housing conditions •Improved sensitivity of integrated approaches for detecting subtle changes in welfare status • Support for data-driven and evidence-based welfare assessment in modern livestock systems 	<ul style="list-style-type: none"> • Variable accuracy and reliability of different groups of parameters • Difficulty in standardizing behavioral indicators • Physiological data often require invasive or semi-invasive measurement methods • Environmental parameters do not always directly reflect the animal’s physiological state • High dependence on data quality and proper sensor calibration • Possible interpretational ambiguity of certain indicators •Heterogeneity of data sources complicates integration and comparative analysis •Limited validation of some indicators under real farm (field) conditions
O - Opportunities	T - Threats
<ul style="list-style-type: none"> • Integration of all parameter groups into a unified AI-based sheep welfare assessment model • Use of predictive analytics to forecast stress and diseases • Development of Precision Livestock Farming (PLF) systems • Creation of digital sheep welfare indices • Automation of monitoring processes without human intervention • Application of Big Data for building reference behavioral models 	<ul style="list-style-type: none"> •Incorrect interpretation of behavioral data by AI models • Sensor errors under field conditions • Insufficient adaptation of models to different sheep breeds • Environmental factors may mask the real physiological condition of animals • Cybersecurity threats and potential loss of monitoring data •High cost of implementing integrated monitoring systems

<ul style="list-style-type: none">• Improvement of early warning systems for health and welfare risks Expansion of real-time decision-support tools for herd management	<ul style="list-style-type: none">• Dependence on technological infrastructure and system reliability• Risk of over-reliance on automated systems instead of expert validation
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The obtained results indicate that the implementation of artificial intelligence technologies significantly improves the accuracy, efficiency, and objectivity of sheep welfare assessment, enabling a transition toward continuous monitoring and predictive diagnostics systems. At the same time, it has been established that the effectiveness of such approaches depends on parameter standardization, data quality, and the adaptation of algorithms to different animal housing conditions.

The conducted SWOT analysis confirms the feasibility of further development of integrated digital systems for sheep welfare assessment within the context of modern precision livestock farming and sustainable development concepts.

Conclusions. The current state of scientific research in sheep welfare assessment demonstrates a clear transformation from traditional zootechnical and visual-expert approaches toward high-tech digital monitoring systems based on artificial intelligence, sensor networks, and predictive analytics. The most structured approach is the division of sheep welfare parameters into three key blocks: behavioral, physiological, and environmental, which are considered as an interconnected system of indicators. It is emphasized that the integration of these blocks into a unified digital model enables the most reliable assessment of animal condition, as the isolated use of individual indicators leads to a loss of diagnostic accuracy.

Modern approaches involve the use of computer vision, video analytics, and deep learning algorithms for automatic recognition of behavioral patterns, including changes in locomotor activity, social interactions, feed intake, and deviations from normal flock behavior. Behavioral changes may precede clinical manifestations of disease by 24–72 hours, forming the basis of early warning systems.

Physiological parameters are considered highly accurate but technologically complex for continuous monitoring. A key trend is the shift toward the use of non-invasive wearable IoT devices, which enable continuous data collection without additional stress to the animal. The integration of physiological data with behavioral signals significantly improves the accuracy of pathological condition diagnosis.

Environmental parameters are considered an active determinant of animal welfare. The role of climate change is particularly emphasized, as it increases the importance of environmental monitoring in livestock production.

The use of machine learning algorithms, neural networks, and computer vision methods enables not only the classification of the current animal condition but also the prediction of risks of disease development, stress responses, and productivity decline. Of particular scientific value are multimodal models that integrate different types of data (video, sensor-based, physiological, and environmental), providing high predictive accuracy.

Further development of this field requires the strengthening of the methodological framework, standardization of parameters, increased transparency of artificial intelligence algorithms, improvement of multimodal models, and broader practical implementation under production conditions, as well as their adaptation to different management systems and climatic environments.

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ПАРАМЕТРИ ОЦІНЮВАННЯ БЛАГОПОЛУЧЧЯ ОВЕЦЬ З УРАХУВАННЯМ СУЧАСНИХ ПІДХОДІВ У КОНТЕКСТІ ШТУЧНОГО ІНТЕЛЕКТУ ТА ПРОГНОЗНОЇ АНАЛІТИКИ

Анотація

У статті розглянуто сучасні підходи до оцінювання благополуччя овець із застосуванням технологій штучного інтелекту (ШІ) та прогнозної аналітики. Узагальнено традиційні та інноваційні параметри welfare-оцінювання, включаючи поведінкові, фізіологічні, продуктивні та екологічні індикатори. Обґрунтовано доцільність інтеграції цифрових технологій, сенсорних систем і алгоритмів машинного навчання для формування об'єктивної, безперервної та багатофакторної оцінки стану тварин. Встановлено, що найбільш перспективним є мультипараметричний підхід, який поєднує фізіологічні, поведінкові, екологічні та продуктивні індикатори. Показано, що інтеграція технологій Precision Livestock Farming (PLF), сенсорних систем та алгоритмів машинного навчання дозволяє здійснювати безперервний моніторинг і прогнозування стану тварин у реальному часі. Обґрунтовано необхідність створення цифрових моделей оцінювання благополуччя овець на основі штучного інтелекту.

Ключові слова: *благополуччя овець, параметри, штучний інтелект, прогнозна аналітика, precision livestock farming, One Health.*

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