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Dochkin Dmytro Oleksiiovych, Applicant for Higher Education at the Faculty of Biotechnology
Dnipro State Agrarian and Economic University; Ukraine

Scientific supervisor: Mylostyvyi Roman Vasylovych, PhD in Veterinary Sciences, Associate Professor of the Department of Animal Feeding and Breeding Technologies
Dnipro State Agrarian and Economic University; Ukraine

FROM STRESS BIOMARKERS TO INTEGRATED ASSESSMENT OF ADAPTIVE RESPONSES IN CATTLE

The assessment of adaptive responses in cattle is an important component of animal health monitoring and sustainable livestock management. Under intensive production conditions, animals are exposed to environmental, physiological and technological challenges that may affect their functional state, productivity and reproductive performance. Although stress responses are commonly evaluated using individual physiological or behavioural indicators, adaptation involves interactions between several biological systems. Consequently, a comprehensive assessment requires consideration of both the intensity of environmental exposure and the responses expressed at different levels of biological organisation.

Individual differences in stress responsiveness have been demonstrated through productive and reproductive characteristics. Research involving Ukrainian Red Dairy cows identified differences in the technological properties of milk obtained from animals with different levels of stress resistance. Milk from cows characterised by lower stress resistance showed less favourable properties for rennet cheese production, indicating that physiological susceptibility to stress may also influence the processing characteristics of animal products [1]. Similar variability has been reported in breeding bulls, where differences in stress resistance were associated with morphometric and histological characteristics of the reproductive organs and semen quality [2]. These observations suggest that stress responsiveness is relevant not only to immediate physiological regulation but also to economically important functions.

Endocrine indicators provide information about the internal mechanisms involved in stress adaptation. Cortisol is a major component of the hypothalamic–pituitary–adrenal response and participates in metabolic and physiological adjustments to challenging conditions. Research on dairy cows exposed to acute and chronic heat stress has demonstrated changes in serum cortisol concentrations, supporting its relevance as an indicator of endocrine responses to thermal exposure [4]. Nevertheless, cortisol concentration is influenced by the timing of sampling, the duration of exposure and other physiological factors. Its interpretation therefore requires consideration of the conditions under which measurements are obtained.

Haematological indicators provide another perspective on the biological consequences of environmental stress. Prolonged heat exposure may alter the distribution of circulating leukocytes and the balance between different components of immune defence. In Holstein cows exposed to heat stress for 45 days, the proportion of band neutrophils increased 2.2-fold, while lymphocyte and monocyte counts decreased by 24% and 42%, respectively. The Nuclear Shift Index increased by 79%, accompanied by changes in indices reflecting adaptive immune responses [6]. These findings demonstrate that composite leukocyte indices can reveal alterations in immune regulation that may not be adequately characterised by total leukocyte counts alone.

However, endocrine and haematological measurements generally depend on periodic sampling. They provide valuable information about the physiological state at a particular time but are less suitable for continuous observation of changes occurring between examinations. Behavioural indicators can complement laboratory measurements because they reflect animal activity under routine production conditions. Rumination is particularly relevant owing to its relationship with feeding behaviour, digestive function and general animal health.

Recent developments in sensor technology have expanded opportunities for objective rumination monitoring. A study involving 19 Holstein Friesian cows demonstrated that individual rumination cycles and regurgitation events could be identified using a sensor incorporating pressure measurements and a triaxial accelerometer. Agreement between sensor-based identification and visual observations was high, with sensitivity ranging from 99.1% to 100% and specificity from 87.8% to 95%. However, classification performance depended on the frequency of data transmission [3]. These findings illustrate both the potential of automated behavioural recording and the importance of technical validation before such measurements are incorporated into practical monitoring systems.

The interpretation of physiological and behavioural responses also depends on the environmental conditions experienced by animals. Heat stress provides a useful example because its effects are influenced not only by the intensity of thermal exposure but also by its duration and the opportunity for recovery. The temperature–humidity index (THI) is widely used to characterise environmental heat load, although a single THI value cannot fully describe the biological consequences of exposure.

An integrated assessment developed for dairy herds combined THI measurements with milk productivity, dry matter intake and clinical indicators, including mastitis and lameness. The analysis demonstrated that maximum daily THI, cumulative heat load and elevated night-time THI were associated with different aspects of production and welfare. Incorporating animal-related indicators improved the explanatory capacity of environmental models and provided a broader interpretation of heat-related risks [5]. This supports the distinction between measuring a potentially stressful environment and determining its actual consequences for the animals exposed to it.

The combined interpretation of these findings suggests that adaptive responses should be considered across several complementary dimensions. Endocrine measurements characterise regulatory activity, leukocyte indices reflect changes in immune status, and behavioural observations provide information about functional activity under production conditions. Productive and reproductive characteristics represent additional outcomes through which the consequences of stress may become apparent. Each group of indicators

contributes different information, while none can independently provide a complete assessment of adaptive capacity.

An important methodological consideration is the distinction between stress responsiveness and stress resilience. A pronounced physiological response does not necessarily indicate poor resilience, because temporary endocrine or immune changes may form part of normal adaptation. Conversely, the absence of an immediate measurable response does not guarantee that productive or reproductive functions will remain unaffected during prolonged exposure. Evaluation of resilience therefore requires attention to the magnitude, duration and consequences of biological responses, including the ability to maintain or recover important functions.

Precision livestock technologies offer opportunities to improve such assessments by increasing the frequency and continuity of animal observation. Automated behavioural monitoring can complement periodic laboratory investigations, while environmental measurements provide the context necessary for interpreting observed changes. Nevertheless, integration of these information sources requires appropriate validation, consideration of individual variability and recognition that associations between indicators do not necessarily establish causal relationships.

From a practical perspective, a multilevel assessment may support earlier identification of animals requiring additional attention. Changes in rumination or other behavioural characteristics could prompt targeted physiological or veterinary examination, while endocrine and haematological findings may help clarify the biological nature of the response. Environmental and production records can subsequently provide information about the conditions associated with these changes and their consequences for herd performance.

In conclusion, stress adaptation in cattle involves interconnected endocrine, immune, behavioural and productive responses. Combining physiological biomarkers with behavioural and environmental monitoring provides a more comprehensive assessment of stress resilience and supports the development of precision herd management strategies.

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