Received 11.02.2026 Revised 08.05.2026 Accepted 24.06.2026 Published: 14.08.2026

Vol. 22, No. 4
2026

Scientific Reports of the National University of Life and Environmental Sciences of Ukraine

Journal homepage: https://scireports.com.ua/en e-ISSN 2223-1609

UDC 636.2.084:005.52 DOI: 10.31548/dopovidi/4.2026.107

Methodological protocol for conducting a cow feeding audit as a tool for realising the genetic potential of animals

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Abstract. In modern industrial dairy farming, the full realisation of the genetic potential of animals remains a complex challenge. In practice, actual productivity often does not correspond to theoretical calculations because of technological errors, unaccounted environmental factors, and hidden disturbances in the system of supplying animals with nutrients. This determines the need to introduce

Suggested Citation:
Borshchenko, V., Lavryniuk, O., Bernatskyi, A., Sharpatyi, O., & Sikhnevych, K. (2026). Methodological protocol for conducting a cow feeding audit as a tool for realising the genetic potential of animals. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine*, 22(4), 107-126. doi: 10.31548/dopovidi/4.2026.107.

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systematic auditing as a tool for operational control and correction of production processes. The purpose of the study was to provide a theoretical and methodological justification for a comprehensive protocol for auditing the feeding system to identify technological discrepancies and to create a conceptual model for organising experimental studies and interpreting their results correctly. The study was based on a systems approach to evaluating the entire feeding chain. The methods used included comparative analysis, zootechnical control, and interpretation of biochemical indicators of the physiological state, particularly milk urea level. A detailed audit algorithm consisting of six sequential steps was developed. The first stage involved a detailed analysis of the current situation by comparing calculated rations with actual productivity data and reproduction indicators. Feed quality was assessed in parallel, including an audit of storage conditions, conservation technologies, and the physicochemical properties of ingredients. The next block focused on operational processes of preparing and distributing the feed mixture: loading accuracy, mixing time, and uniform distribution of components are controlled. Intake monitoring involved analysing animal behaviour, assessing the amount of refusals, and identifying separation of feed particles. The final stages included assessment of the physiological state of the herd, particularly body condition, rumen fill, and rumination intensity. The audit ended with a comprehensive interpretation of milk composition. Special attention was given to the use of the urea indicator as a marker of protein and energy use efficiency, which supports prompt correction of feeding. Introduction of the protocol helps specialists identify "bottlenecks" in the production cycle, reduce feed costs per unit of output, prevent the development of metabolic disorders, and ensure maximum realisation of the biological capacity of a high-producing herd

Keywords: technological control; milk urea; feed conversion; physiological state, biological potential; management algorithm; quality of raw milk

Introduction

As of 2025, the intensification of dairy farming requires a complete transition from general methodological approaches to animal keeping towards high-precision herd management technologies. The discrepancy between the actual productivity of cows and their genetic potential remains one of the key technological and economic challenges for the agricultural sector. High-producing animals exhibit extreme sensitivity to the slightest deviations in the structure, uniformity, and physicochemical quality of feed mixtures, which is directly correlated with the profitability and overall financial efficiency of livestock enterprises. The use of standardised approaches without considering the individual metabolic needs and physiological state of the herd leads to latent pathologies, systemic health disorders, and a rapid decline in the reproductive capacity of the breeding herd. The development and introduction of a clear, standardised methodological protocol for auditing the feeding process supports the successful transformation of theoretical ration calculations into high real productivity indicators. This determines the objective need to create effective tools for promptly identifying hidden technological shortcomings in the feeding system and developing effective corrective measures in real time.

During 2020-2025, the optimisation of cow feeding remained a focus for many researchers who concentrated on digital solutions, precision approaches, and accurate monitoring of ethological indicators. In particular, Ukrainian researchers V. Borshchenko *et al.* (2025) examined the digitalisation of diagnostics in livestock farming. Their study concluded that the introduction of mathematical models for ration balancing minimises the destructive influence of the human factor and provides a stable level of energy supply in the animal organism. International researchers M. Mezzetti *et al.* (2021) devoted their work to the analysis of metabolic profiles in high-producing herds. Their research established that a systematic audit of critical points directly affects the productive lifespan of cows since it identifies subclinical ketosis before visible symptoms appear. In the same work, the authors emphasised the critical importance of monitoring the transition period. The data indicated that the largest losses of productive potential occur because of incorrect management of feeding processes during the three weeks before and the three weeks after calving, which requires separate control protocols for this technological group.

The physical structure of feed and separation also received considerable attention during this period. The direct influence of the geometric parameters of particles on rumen stability remained outside the focus of many previous developers of rationing systems. This aspect was analysed in detail by E.K. Miller-Cushon & M.B. Jensen (2025), who examined cattle behaviour during feed intake. The researchers argued that excessive particle length stimulates selective eating, reduces the expected effectiveness of balancing, and provokes fluctuations in the pH level of rumen contents. An important contribution to addressing this problem was made by Ukrainian researchers Yu. Obertiukh *et al.* (2025), who assessed the effect of biologically active additives against the background of basal rations. The study demonstrated that, without a prior detailed audit of feed macro-components and assessment of the physical structure of the mixture, the use of additional components is often economically unjustified. E. Mitev *et al.* (2025) also placed strong emphasis on the precision approach (Precision Dairy Farming). The work emphasised that modern sensor systems for monitoring feed intake support individual auditing of each animal in automatic mode.

A. Lavery *et al.* (2025) investigated in detail the behavioural responses of cows during feeding and rest. They determined that a technological audit protocol should cover not only the composition of the mixture but also the frequency of feed push-up on the feed bunk, since this acts as an additional stimulus for stable intake and supports an optimal forestomach environment. However, D.F. Chapman *et al.* (2025) argued that regional features of the feed base and silage quality are often ignored in global commercial protocols. In the view of the researchers, this requires mandatory adaptation of existing methods to specific geographical and farm conditions.

Overall, the analysis of academic sources from 2020 to 2025 demonstrates a gradual transition from simple calculation of theoretical standards to comprehensive monitoring of all stages, from storage in trenches to the feed bunk, which confirms the practical demand for a complete methodological protocol. This study aimed to provide a methodological justification and develop a comprehensive protocol for operational auditing of high-producing cow feeding to increase the efficiency of transforming ration dry matter (DM) into milk and to maintain animal health.

Materials and Methods

The methodological basis of the work was a system approach to analysing the technological chain of dairy cattle feeding. The study was performed during 2020-2026 at PAE "Novoselytsia" (village of Novoselytsia, Zhytomyr Oblast). A comprehensive approach was applied to develop the audit protocol. The monitoring method was used for an objective assessment of the actual state of feeding. It provided a detailed analysis of discrepancies between planned calculated rations and the actual feed intake of animals. Zootechnical analysis was used to evaluate the quality of feed raw materials, including organoleptic indicators, moisture content, and the physical structure of particles. It also supported assessment of the physiological state of animals, with emphasis on analysis of rumen fill and the intensity of rumination activity in cows. The laboratory analytical method was central to the interpretation of milk urea nitrogen (MUN) indicators. For this purpose, a method based on Fourier-transform infrared spectroscopy (FTIR) was selected, providing mass monitoring with minimal time expenditure. During the study, particular attention was paid to standardising sampling conditions because a direct dependence was established between urea nitrogen concentration and the time of sample collection relative to feeding and the milking sequence number. At the laboratory stage, several nuances were considered to minimise the influence of external factors on the accuracy of results. Specifically, samples were cooled to 4°C immediately after collection to prevent bacterial decomposition of urea to ammonia. During analysis, the fat and protein content of milk was considered, as they can create spectral interference, and equipment calibration was therefore performed using reference chemical methods, particularly the enzymatic colorimetric method according to M. Portnoy *et al.* (2021). These data were used as an important indicator for assessing the efficiency of metabolic processes related to nitrogen use in the rumen.

The methodological justification for assessing nitrogen metabolism was built on the approaches presented in the works of S.M. Godden *et al.* (2001) and J.W. Spek *et al.* (2013). The model developed by these researchers for the relationship between the crude protein level in the ration and urea excretion was adapted in the study. The method of S.M. Godden *et al.* (2001) was used to determine urea threshold values that signal an energy imbalance in the rumen. The calculation algorithms of J.W. Spek *et al.* (2013) were used to correct the obtained indicators for daily milk yield and live weight of animals. The data obtained served as a reliable indicator for assessing the efficiency of metabolic processes related to nitrogen use in the rumen and supported prompt ration correction based on the audit results.

The comparative analysis method was used to compare the data obtained during the audit with established regulatory requirements and to assess the correspondence between productivity indicators and the genetic potential of the herd. NRC (2001) standards and updated NASEM (2021) recommendations were adopted as reference parameters in the study. They define critical levels of DM intake and metabolisable energy concentration for different physiological groups. In particular, the comparison was performed for indicators of neutral detergent fibre (NDF) and rumen-degradable protein, which are basic for maintaining optimal environmental pH and microbial synthesis (NASEM, 2021).

Normative conversion coefficients justified in the works of S. Ruban & V.O. Danshyn (2024) were used to assess the efficiency of feed-component use. This helped determine the degree to which the potential of animals was realised depending on the stage of lactation. Target intervals of MUN, established according to the protocols of A. Bougouin *et al.* (2022), were selected as a reference for analysing nitrogen metabolism and helped identify excessive use of protein supplements or energy deficiency in the ration. The use of these standards, aligned with modern criteria for assessing metabolic state (Zhao *et al.*, 2024), ensured the objectivity of the audit and helped identify hidden reserves for increasing milk productivity.

The object of the study was the process of organising feeding for high-producing Holstein cows. During the development of the audit stages, key technological parameters were considered: accuracy of total mixed ration (TMR) mixing, uniform distribution of feed along the feeding front, and separation of feed particles by animals during the day. Ration formulation was performed using NASEM software and the "Ration Calculator for Farm Animals" (NRC, 2001; NASEM, 2021). The Penn State Particle Size Separator was used to assess the physical structure of the ration. The standardised method of separating feed particles by size was applied, scientifically justified in the work of B.P. Lammers *et al.* (1996), and the approaches of N.B. Cook & K.V. Nordlund (2009) were adapted to assess behavioural aspects and feed-separation risks. In particular, the percentage distribution ranges proposed by the cited researchers for particles on the upper, middle, and lower sieves were used, which enabled quantitative assessment of feed-mixture uniformity and prediction of risks of selective feed intake by animals. The use of this set of tools clarified whether the actual ration structure corresponded to the physiological needs of ruminants, which is critically important for maintaining rumen health and ensuring a stable level of milk fat. These approaches provided for the standardisation of audit results and their comparability with global standards of precision livestock farming.

Within the methodological protocol, separate attention was given to assessing the efficiency of conversion of ration components through starch digestibility analysis. For this purpose, the method for determining residual starch content in faeces (Fecal Starch Analysis) was applied, which quantified the degree of assimilation of the energy component of feed (Fredin *et al*., 2014). The audit calculation models considered the pattern whereby a 1% decrease in faecal starch content causes an increase in daily milk yield of approximately 0.32 kg without the use of additional resources. This focus allowed transforming laboratory analysis results into specific economic indicators and evaluating the level of realisation of the herd genetic potential through the efficiency of the digestive system of animals.

Mathematical modelling of the transformation of ration components into products was used for the quantitative assessment of resource-use efficiency within the audit. The main coefficients were calculated according to the following algorithms. Feed efficiency of conversion of the ration into milk (Feed Efficiency, FE) was used to determine the volume of output produced per unit of consumed feed. The calculation was performed using the formula:

$$\mathrm{FE} = \frac{\mathrm{M\ corr}}{\mathrm{DM\ I}}, \tag{1}$$

where M_{corr} – the average daily milk yield corrected to the standard fat and protein content (Energy-Corrected Milk), kg/day; DMI – dry matter intake, kg/day. Nitrogen use efficiency in milk (Nitrogen Use Efficiency, NUE) – by calculating the ratio of nitrogen secreted in milk to the total amount consumed to evaluate the degree of assimilation of the protein part of the ration and minimise nitrogen losses into the environment. The indicator was determined using the formula:

$$\mathrm{NUE} = \frac{\mathrm{N\ milk}}{\mathrm{N\ intake}}, \tag{2}$$

where N_{milk} – the daily amount of nitrogen secreted in milk (calculated from milk protein content), kg/day; N_{intake} – the total daily amount of nitrogen consumed (calculated from crude protein content in the ration), kg/day.

The use of these formulas, based on the methodologies of R.A. Kohn *et al.* (2002) and P. Huhtanen & A.N. Hristov (2009), provided an objective assessment of the technological level of the farm and established the actual degree of realisation of animal potential. During the audit, the average value of feed conversion was recorded at 1.4 and nitrogen conversion at 0.290, which served as the basis for further optimisation of the feeding structure. Processing of results and development of the audit algorithm were performed through a systematic synthesis of global experience, particularly NRC (2001) and NASEM (2021) recommendations, and the authors' research on ration correction under industrial conditions. The developed protocol was tested under the conditions of PAE "Novoselytsia" (village of Novoselytsia, Zhytomyr Oblast).

Results and Discussion

As a result of research and the systematisation of technological processes in industrial dairy farming, a comprehensive protocol for auditing cow feeding was developed. This protocol integrates visual, zootechnical, and laboratory control methods into a single seven-stage assessment system that identifies discrepancies between calculated ration parameters and actual feed intake (Wathes *et al.*, 2008). A general protocol architecture based on the sequential completion of seven control stages was developed to systematise the control process. This structure transforms the audit from simple observation into a complete system for managing feeding quality.

The first stage covers documentary and calculation audit. It is based on ration formulation using NASEM (2021) software or specialised modelling tools (Borshchenko *et al.*, 2025; Obertiukh *et al.*, 2025). The obtained data are analysed in detail and compared with actual productivity indicators and milk quality characteristics. The second stage is directed at auditing the feed base and raw materials. Specialists check bunker management, paying particular attention to the face condition and aerobic stability of feeds. Physical characteristics are also assessed, especially moisture content and chop length, which are critically important for proper feed intake. The third stage is devoted to the technological audit of TMR preparation. During this period, loading and mixing of components are controlled, and the Penn State sieve test is applied (Lammers *et al.*, 1996). This method identifies separation on the feed bunk, which may adversely affect the uniformity of ration intake (Cook & Nordlund, 2009). The fourth stage covers ethological and physiological audit. It includes assessment of rumen fill to determine the adequacy of feed intake, analysis of rumination activity to check the functioning of structural fibre (Burlaka *et al.*, 2004), and visual assessment of manure consistency. The fifth stage corresponds to morphological audit of transit (excreta). This process focuses on detailed diagnosis of digestibility through manure scoring and washing through sieves. This determines the proportion of undigested grain, the presence of excessively large forage particles, and signs of accelerated transit or ineffective microbiota activity (Gabriella *et al.*, 2005). The sixth stage is directed at biochemical milk monitoring or laboratory verification of biomarkers. An important component is MUN monitoring for controlling nitrogen and energy balance (Godden *et al.*, 2001; Spek *et al.*, 2013). The dynamics of fat and protein content are also analysed, which supports assessment of the overall efficiency of assimilation of consumed substances (Zhao *et al.*, 2024). The seventh stage consists of correction and forecasting. Deficiencies are eliminated based on the detected technological errors (undigested grain, MUN deviation, or feed separation). The ration is recalculated and further adapted using modern models (NASEM, 2021), which creates the conditions for full realisation of the genetic potential of animals.

The proposed protocol architecture (Fig. 1) has a closed control cycle. Direct links represent the physical movement of feed from storage to the animal organism, while reverse arrows from the biochemical and morphological control modules (Feedback Loops) provide operational correction of ration input parameters. This transforms the feeding system into a self-regulating process aimed at minimising technological losses (Wathes *et al.*, 2008). A feeding audit involves the sequential implementation of stages to assess the state of the herd and the efficiency of production processes. The primary task is a detailed analysis of the animal population on the farm, considering breed composition, lactation phase, and the current production cycle. Productivity indicators (milk yield), live weight, and body condition score (BCS) are necessarily recorded. The qualitative characteristics of milk are also examined, particularly fat, protein, and urea content (Godden *et al.*, 2001; Nousiainen *et al.*, 2004), and excreta are assessed on a five-point scale (Neitz & Robertson, 1991), which supports conclusions about digestive-system functioning.

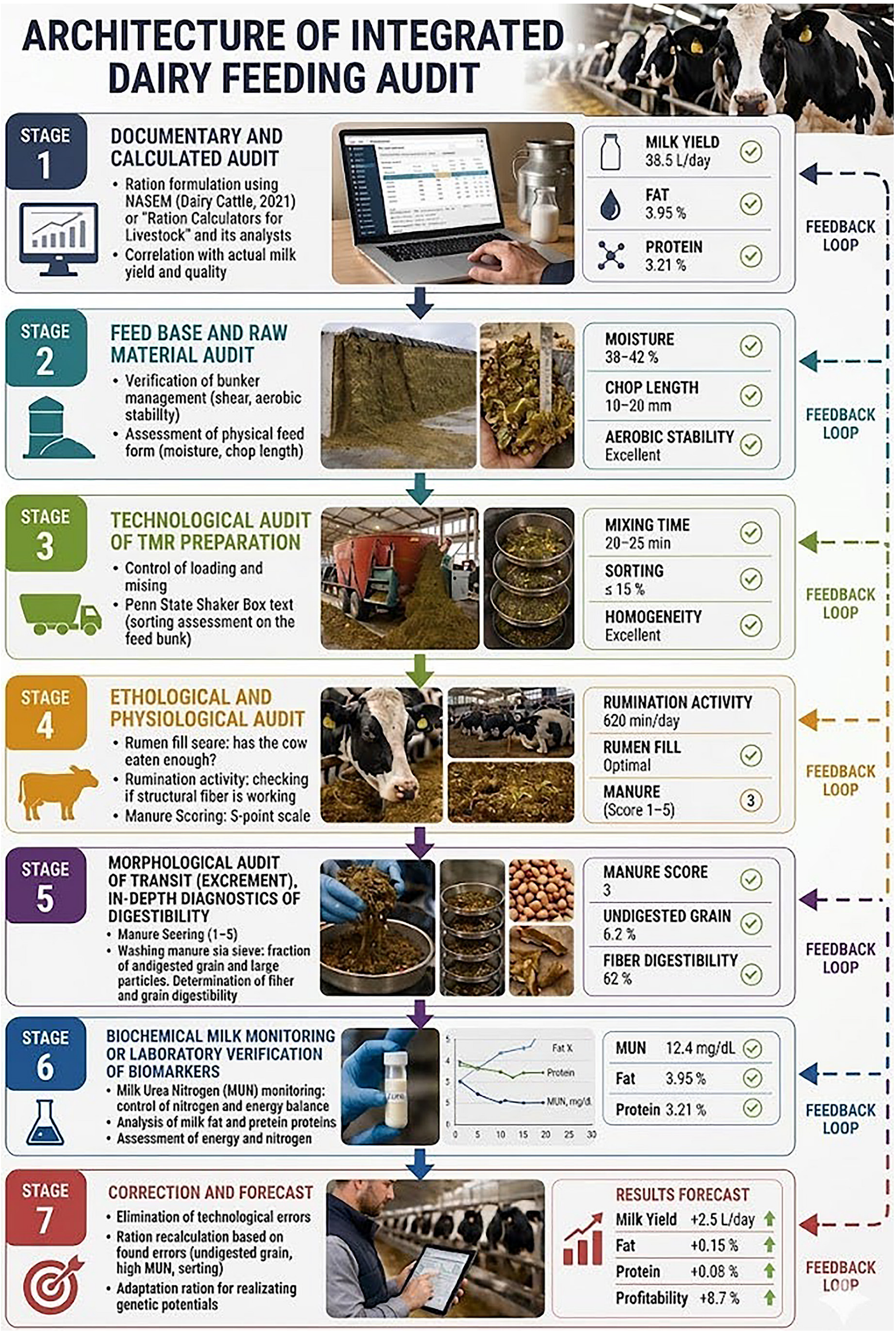

Figure 1. *Conceptual model of an integrated feeding-system audit for high-producing cows*
Source: developed by the authors

The next step is recording the feed actually consumed and performing a detailed component analysis of the farm ration. This establishes the real level at which animals are supplied with components needed to maintain productivity and identifies discrepancies between calculated plans and actual intake (NRC, 2001). Based on data on the amount of feed distributed, refusals, and DM content in the TMR, the amount of feed consumed as-fed and as DMI per head is determined. These data are entered in the technologist'sinformation system or calculated directly during the audit.

The component composition of the ration, previously formed using NASEM (2021) software or specialised modelling tools (Borshchenko *et al*., 2025; Obertiukh *et al*., 2025), is then analysed. The analysis is performed by main feed groups: roughages (hay, haylage, silage, straw, pulp), energy feeds (compound feed, cereals, cornage, molasses), protein feeds (soybean meal, sunflower cake, brewer's grains), and mineral-vitamin additives and premixes (Table 1).

Table 1. *Feed composition of dairy cow rations and productive effect of feeds*

Composition of rations	**Rations**	
	kg as-fed feed	**kg dry matter**
Main feeds		
Hay	1.5	7.0
Alfalfa haylage	3.5	7.7
Maize silage	27	48.8
Barley straw		
Sour pulp		
Energy feeds		
Compound feed		
Cereal meal	6.2	30.6
Cornage		
Molasses		
Protein feeds		
Soybean meal	0.8	3.9
Sunflower cake		
Brewer's grains		
Pea meal		
Feed additives		
Table salt	0.1	0.5
Premix	0.25	1.4
Amount of concentrates in ration, % of DM		34.5
Concentrate use per 1 kg milk, kg	0.350	

Source: developed by the authors

At the end of the table, the proportion of concentrated feeds in the ration and their use for producing 1 kg of milk are indicated. This determines the share of concentrates in the production structure. Monitoring of animal excreta is defined as a key tool for diagnosing the efficiency of digestive processes, as manure is an integrated indicator of assimilation of consumed feeds (Neitz & Robertson, 1991). The examination of the physical properties of faecal matter supports assessment of the degree of starch and fibre conversion, detection of violations in the processing technology of grain raw material, and diagnosis of risks associated with an excessive level of concentrates in the ration (Gabriella *et al*., 2005).

Visual assessment of faecal consistency is a primary method for diagnosing the metabolic state of the herd. Liquid excreta often indicate the development of acidotic disorders caused by excess readily available carbohydrates in the ration and accompanied by a decrease in rumen pH (Broderick, 2003). Conversely, normal dense faecal consistency corresponds to effective digestion, which creates preconditions for gradually increasing the proportion of concentrates in the ration to stimulate milk productivity without the risk of destabilising digestive processes (Neitz & Robertson, 1991).

Visual analysis of faecal consistency on a 1 to 5 score scale is used to monitor the physiological state of digestion (Neitz & Robertson, 1991). According to this method, a score of approximately 3 is considered optimal and corresponds to a state in which faeces form a specific "dome" with a slight depression in the middle. Values within 1-2 points indicate overly liquid consistency, signalling a risk of acidosis because of excess fractions of "fast" starch or fine particles in the ration (Broderick, 2003). Scores of 4-5 points indicate excessively thick consistency, signalling a deficiency of fermentable energy or water, excess non-digestible fibre (NDF), and generally low feed digestibility. The average score for each section should be recorded weekly to monitor the dynamics of metabolic processes and track changes in the corresponding animal groups.

An additional diagnostic tool is the rapid "wet sieving" test, which takes 5-7 minutes. The procedure involves using a #16 laboratory sieve with a mesh size of 1.18 mm, on which approximately 200-300 grams of fresh manure are washed under a weak stream of water. During the analysis, attention is paid to the presence of whole or half grains, large fragments of maize hulls, and long undigested fibres (Gabriella *et al*., 2005). A considerable number of such particles larger than 1-1.6 mm is a sign of insufficient feed preparation, a low kernel processing score (KPS), or improper grinding of grain components (NASEM, 2021).

Faecal starch analysis is a tool for forming an accurate energy-related conclusion about farm production activity. This indicator objectively reflects the efficiency of feed assimilation in the living organism, unlike theoretical data in calculation tables. High feed conversion efficiency is directly correlated with milk productivity: a 1% decrease in faecal starch content was established to cause an increase in milk yield of approximately 0.3 kg per day without additional resources.

It was established that, under normal conditions, starch concentration in the faeces of high-producing cows should be approximately 3%, indicating an optimal level of fermentation in the rumen and subsequent assimilation in the small intestine. Each +1% deviation above this threshold leads to a loss of approximately 0.32 kg of milk per cow daily (Fredin *et al*., 2014). The calculation models presented in the works of M.L. Eastridge *et al.* (1998) and confirmed by modern practical studies by S.M. Fredin *et al.* (2014) were used to justify this indicator methodologically in the results section. In particular, these authors indicate that faecal starch content above 5% is a critical marker of technological errors in preparing the grain part of the ration, such as insufficient grinding or rolling, or digestive disturbances requiring immediate auditing and correction of the feed-mixture structure.

The use of these parameters provided an accurate calculation of lost profit resulting from incomplete assimilation of feed energy, which corresponds to the principles of precision livestock farming (Mitev *et al*., 2025). This approach transforms laboratory analysis results into an operational management tool aimed at increasing the economic efficiency of production. If the starch level exceeds 3%, a comprehensive audit of technological processes is needed, including verification of KPS, which should be at least 70%, evaluation of the grinding degree of dry or moist grain, monitoring of the TMR profile using the Penn State Particle Separator (PSPS), and control of feeding and intake rates (Cook & Nordlund, 2009; NASEM, 2021). Typical causes of increased starch content include excessively fine grinding, which provokes rapid fermentation and the development of acidotic states with a decline in milk fat, or, conversely, insufficient grain processing, which leads to the transit of whole kernels through the gastrointestinal tract and subsequent energy loss (Jenkins, 1998).

Effective feeding requires correlation with indicators from previous stages (upstream KPIs):

- KPS of maize silage (the target level is ≥70%, and for high-producing groups, achievement of 75% or higher is recommended (NASEM, 2021).
- PSPS profile (the particle distribution should be maintained within the defined "green corridor" for the upper and middle sieves and the pan, minimising feed separation expressed as the difference between the theoretically calculated ration composition and its actual consumption on the feed bunk (Cook & Nordlund, 2009).
- uNDF240 analysis (regular checking of the proportion of indigestible fibre in basal feeds is mandatory because its excess increases the risk of faecal matter with a consistency of 4-5 points and a decrease in available ration energy (NASEM, 2021).

Systematic monitoring of these indicators identifies critical points in feeding technology and supports timely measures to optimise feed digestibility (Wathes *et al*., 2008). A clear sampling protocol and monitoring schedule were followed to ensure data reliability. Material for analysis was collected by taking samples from six to ten points in the group three to six hours after distribution of the TMR, after which a pooled sample was formed. Visual assessment and the wet sieving test should be performed weekly, while laboratory analysis of faecal starch content – monthly or more often when silage or grain quality changes. A form recording the date, animal group, obtained score, presence of undigested grains or fibres, and list of measures taken was used to systematise the results.

Actions taken when deviations were identified focused on eliminating the causes that led to deterioration in digestive indicators. When liquid manure was detected (1-2 points), the proportion of fast starch or fine fraction in the ration was lowered, effective fibre was added (Burlaka *et al*., 2004), and the frequency of feed distribution was optimised. If manure consistency was excessively thick (4-5 points), fibre digestibility and the proportion of long particles (PSPS) were reviewed, and free access to water was ensured. In cases where whole grains were detected in faeces, grinding or maize-processing technology was corrected immediately. Following these recommendations minimises the risks of metabolic disorders and ensures stable efficiency of bioconversion of ration components into milk products (Wathes *et al*., 2008). The monitoring results served as the basis for further optimisation of the nutrition structure and quantitative assessment of the contribution of individual ration components to the overall milk yield.

The next step in the management audit system was the calculation of the productive effect of basal and concentrated feeds (Table 2). The methodology of these calculations is based on a differentiated approach to determining the contribution of each ration component to the volume of output obtained (NRC, 2001; NASEM, 2021). In this analysis, the productive effect of concentrated feeds was taken as a constant (1.6 kg of milk per 1 kg of consumed concentrate DM), which deductively identified the share of milk obtained from the potential of basal feeds.

The results of the study established that milk production from basal feeds varies considerably: from 60% (up to 5 thousand kg) when high-quality forage is used to 25% when its quality decreases. The economic importance of this difference was defined as substantial for the overall profitability of the enterprise.

It was established that conversion of basal feed in advanced enterprises is approximately 1.2 kg of milk per 1 kg DM, while in most farms this indicator ranges within 0.68-0.86 kg. This difference points to considerable potential for ration optimisation through improved quality of bulky feeds and greater accuracy in their feeding. These levels of dry-matter use efficiency are justified in analytical materials based on comparison of farms with different levels of technological provision (Agnew & Yan, 2000). Data on low conversion, at the level of 0.7-0.8, in less-intensive farms are also confirmed in studies emphasising that low fibre digestibility is the main factor limiting this indicator (Gondo, 2025; Zhou *et al.*, 2025).

The possibility of achieving a high conversion level through the use of high-quality silage and a balanced ration composition has been demonstrated in systematic reviews by Eastridge (2006) and Chowdhury *et al.* (2025). Specifically, it was established that optimisation of the physical structure and energy density of feed brings actual productivity as close as possible to the genetic potential (Ruban & Danshyn, 2024). The use of these indicators within the audit identified the technological gap between the actual state of production and the potentially achievable productivity level. The calculations presented in Table 2 show that the farm under analysis obtained 0.9 kg of milk from 1 kg DM of basal feeds. Alongside quantitative indicators, an important marker of nitrogen-use efficiency is the level of urea in milk (Godden *et al.*, 2001; Spek *et al.*, 2013).

***Table 2.** Calculations of the productive effect of basal feeds*

Indicators	Ration
Milk obtained from concentrates, kg	10.1
Milk obtained from 1 kg DM of basal feeds, kg	0.9

Source: developed by the authors

These calculations indicate that, at the overall productivity level achieved on the farm, the share of milk obtained directly from concentrated feeds is 10.1 kg. By comparing this indicator with the actual milk yield, the contribution of roughages and succulent feeds to the total energy value of the ration can be separated (NRC, 2001; NASEM, 2021). In particular, the analysis of basal-feed use efficiency demonstrated that each kilogram of their DM provides 0.9 kg of milk. This productive-effect value indicates the quality and nutritional value of the basal part of the ration and its capacity to support metabolic processes in the animal organism at the required level. The obtained data enable specialists to objectively assess the conversion efficiency of components and correct feeding to improve the overall results of the farm. The proposed method supports objective determination of the actual productive effect of basal feeds and comprehensive assessment of their quality on the farms under analysis. In addition to quantitative milk-yield indicators, the milk protein level, which under standard conditions is 3.2% (Huhtanen & Hristov, 2009), was defined as an important marker of feeding efficiency. A decline in this indicator is an important sign of deterioration in the quality of the main ration components and the development of an energy deficit in the organism (Broderick, 2003).

The next stage of the audit is analysis of information on daily component intake and their concentration in one kilogram of ration DM (Table 3). Particular attention is paid to determining DM content in the TMR, whose recommended level is 45-55% (Cook & Nordlund, 2009). Adherence to these parameters is critically important because excessive feed moisture reduces its energy value, which becomes especially dangerous during preparation for calving, when the animals' need for nutrients reaches its peak. Conversely, insufficient moisture in the TMR provokes component sorting, which considerably increases the risk of acidosis because of an imbalance in the consumed feed.

The study examined the energy concentration in cow rations, which may range from 7 to 12 MJ ME/kg DM and depends entirely on the quality of basal feeds and the amount of concentrates (NRC, 2001). For high-producing cows, the recommended level of net energy for lactation (NEL) is 1.65-1.70 Mcal/kg DM, or 6.9-7.1 MJ/kg DM (NASEM, 2021). Energy deficiency reduces milk yield, slows recovery of body weight after calving, and delays restoration of the reproductive cycle (Broderick, 2003). The energy concentration in the ration indicates the level of energy nutrition and is reflected in animal body condition and milk protein content. Excess energy in the ration promotes accumulation of adipose tissue, which can lead to obesity in cows. This creates an additional burden on the organism and increases the risk of metabolic disorders in the postpartum period (Wathes *et al.*, 2008).

Table 3. *Daily intake of nutrients and their content in 1 kg dry matter of rations (%)*

Indicators	Contained in 1 kg DM of total mixed ration	Daily intake	Target values
Amount of dry matter, kg	0.50	16.63	45-55%
Metabolisable energy, MJ	10.7	178	8-12 MJ/kg DM
Net energy of lactation, MJ	6.5	108	>6.8 MJ/kg DM (fresh period)
Crude protein, g	130	2,166	16% (high-producing lactating cows)
RDP, %			9-10% DM
RNB, g nitrogen per day		1-50	
Amino acid balance (LYS:MET)			3
Crude fibre, g	187	3,105	≥15
NDF			≥30%
peNDF *			≥20%
Sugar+starch, g	326	5,407	20-45%
Crude fat, g	36	595	3-5% of dry matter
LCFA **			≤2.6%
Calcium (Ca), %			0.70-0.90%
Sulphur (S), %			0.20-0.25%
Vitamin A, KIU/kg DM			8-10 KIU/kg DM
Vitamin D, KIU/kg DM			2-3 KIU/kg DM
Vitamin E, IU/kg DM			100 IU/kg DM

Note: * – physically effective neutral detergent fibre (peNDF) is the fraction of neutral detergent fibre (NDF) that stimulates chewing activity and promotes the formation of a floating mat of large particles in the rumen. The concept of peNDF was developed by Mertens (1997) in the USA. As a concept of feed structure, it combines NDF. The peNDF indicator is calculated by multiplying NDF content by the physical effectiveness factor (pE); ** – long-chain fatty acids (LCFA)
Source: developed by the authors

The crude protein level in the ration was also analysed. It may vary widely, from 9.0 to 17%, depending on the amount of protein feeds and the quality of the basal feed (Huhtanen & Hristov, 2009). The target range was set at 16-18% (NASEM, 2021). Control of the crude protein level is also recommended through milk urea content (Godden *et al.*, 2001; Nousiainen *et al.*, 2004). If the proportion of crude protein in ration DM is 16%, this is considered sufficient (Broderick, 2003).

Excess crude protein in the ration of fresh cows may lead to:

- liver stress, reduced reproductive capacity, and risks of metabolic overload;
- an increase in urea levels in milk and blood, which may adversely affect reproductive function (Spek *et al.*, 2013);
- reduced efficiency of ration energy use.

Excess protein creates an additional burden on the liver because excess ammonia must be utilised. This not only consumes energy needed for lactation but also increases the risk of metabolic diseases. The correct ratio of protein to other components is critical to maintaining liver health and general metabolism. A low protein level, however, critically limits milk protein synthesis.

The balance between RDP (rumen-degradable protein) and RUP (bypass protein) is important.

It was established that RDP should be 9-10% DM to support microbial fermentation in the rumen, through which microbial protein, the main source of amino acids, is synthesised (NASEM, 2021). An insufficient level of RDP limits this process, reducing energy use and fibre digestibility. Rumen microorganisms require energy and protein to create microbial protein. Rumen nitrogen balance (RNB) is defined as a unit for measuring bacterial nitrogen supply with regard to feed energy. Negative RNB indicates nitrogen deficiency: microorganisms have energy available that could produce more microbial protein if protein were supplied. Positive RNB (from 1 to 50) confirms sufficient nitrogen supply, but a value above 100 indicates the risk of alkalosis. A positive RNB can be reduced by adding extra energy to the ration. Exceeding the permissible RNB limit of 60 g signals excess ammonia formation, which leads to lost milk production and liver disease.

Microbial protein together with undegraded protein from the basal feed forms absorbed protein in the intestine. These nutrient indicators can be determined in the laboratory or calculated (NASEM, 2021). The amino acid balance (LYS:MET) should be maintained at 3:1. The addition of protected lysine and methionine provides the required ratio for milk protein synthesis (NASEM, 2021). It was established that optimal amino acid balance increases protein-metabolism efficiency by 10-15%.

The fibre-level analysis established that the minimum level of acid detergent fibre (ADF) should be 19-21%, and NDF should be not lower than 26-28% of DM (NRC, 2001; Tyasi *et al.*, 2015;). An insufficient fibre level (NDF < 30% and peNDF < 17-20%) reduces rumination activity (Cook & Nordlund, 2009). The addition of 0.5 kg of alfalfa haylage increases the peNDF level to target values (⩾20%), reducing the risk of subclinical acidosis by 30%.

The amount of sugar and starch in rations usually ranges from 20 to 45% (Gabriella *et al.*, 2005). Excess fermentable carbohydrates, above 45%, create a risk of acidosis (Broderick, 2003). The recommended starch level is 22-28%. The importance of distinguishing between ruminal starch, as a source of VFA, and intestinal starch, as a source of glucose, was highlighted. Balance between them is critical for preventing acidosis and energy losses (Wathes *et al.*, 2008). The content of crude fats also determines feeding safety. If the LCFA level exceeds 2.8%, fibre digestibility may be impaired. It is recommended to maintain LCFA at ⩽2.6% and use inert fats (C16:0 palm oil) to preserve energy without damaging the rumen (NASEM, 2021).

The vitamin-mineral profile is a powerful component of metabolism. The Ca level should be 0.70-0.90% (NRC, 2001), and sulphur (S) should be 0.20-0.25% (NASEM, 2021). Maintaining optimal levels of vitamins A, D, and E strengthens the immune system and minimises the risks of disorders (Wathes *et al.*, 2008). Systematic control of milk quality (Table 4) established a direct relationship between the feeding level and physiological state. The standard for DM intake is 3.6-4.0% of live weight (NRC, 2001). Any deviation from these parameters reduces fat and protein synthesis (Berner, 1993). Insufficient DM intake limits the realisation of genetic potential and worsens milk quality indicators (Huhtanen & Hristov, 2009).

Table 4. *Chemical composition of cow milk and efficiency of nitrogen conversion into milk*

Indicators	Ration
Crude protein level in the ration, % of DM	13.0
Dry matter intake, kg	16.6 ± 0.49
Dry matter intake, % of body weight	2.8
Milk yield, kg	20.0 ± 1.78
3.5% fat-corrected milk yield	22.6
Milk fat, %	3.96 ± 0.19

Table 4. *Continued*

Indicators	Ration
Milk protein, %	3.14 ± 0.07
Lactose, %	4.62 ± 0.03
Milk urea nitrogen, mg/100 ml	9.0 ± 0.03
Milk urea = MUN*2.14, mg/100 ml	19.3
Predicted milk urea nitrogen level, mg/100 ml	8.0
Feed conversion efficiency into milk, yield/dry matter intake	1.4
Nitrogen conversion efficiency into milk, milk nitrogen/daily nitrogen intake	0.290

Source: developed by the authors

As energy intake increases and the fibre level in rations decreases accordingly, milk fat content decreases and protein content increases (Jenkins, 1998). Conversely, when the fibre level increases and energy decreases, milk protein synthesis is suppressed and milk fat synthesis increases. Limited energy intake may reduce milk protein by 0.1-0.4% (Tyasi *et al*., 2015).

A milk protein content of 3.10-3.14% in cow milk, with a standard of 3.2%, indicates a somewhat insufficient energy level in the rations. This may be associated with an insufficient amount of concentrates in the rations, 250-300 g/kg milk, insufficient feed intake, and lower quality of basal feeds. If the milk protein level corresponds to the target value of 3.21%, this indicates high quality of the basal feed and an adequate level of energy supply in the rations.

The minimum content of acid detergent fibre in the ration should be 19 to 21%, NDF – not lower than 26-28% of ration DM (NRC, 2001), and crude fibre – not lower than 15%. If the amount is below these target levels, milk fat content may decrease in cow milk, and acidosis, lameness, and deterioration of the general state of the organism may occur. If the amount of basal feeds and physical and structural fibre is sufficiently high, this naturally affects high milk-fat indicators. Data on fat content in cow milk (3.96%) indicate that the ration is well supplied with fibre.

Farm rations containing different levels of crude protein, through the quality of basal feed and the inclusion of different amounts of protein feeds in rations, directly affect feed intake, milk yield, milk component composition, and feed conversion efficiency into milk.

Notably, excessive feeding of cows with crude protein occurs during ration formulation due to inadequate monitoring of ration and feed management practice. A slight shortage of crude protein may reduce milk protein content by approximately 0.0-0.2%, whereas a larger crude protein deficit may have a stronger effect. With an excessive amount of crude protein in the ration, the amount of protein in milk does not increase because excess protein is excreted from the organism, while milk urea content increases. Excess MUN (>12.0 mg/100 ml) may indicate either a protein imbalance or excess in the ration, or carbohydrate deficiency and insufficient microbial protein synthesis in the rumen (Hutjens & Chase, 2012). Dairy cattle are usually fed rations with a protein level above 16% to ensure maximum milk output (NRC, 2001). This practice contributes to relatively low nitrogen-use efficiency in dairy cattle (Huhtanen & Hristov, 2009) and may reduce profit margin (Godden *et al*., 2001).

The MUN level indicates that the crude protein level in the rations of animals on the farm is probably too low (MUN = 9.0 mg/100 ml). The optimal level of urea nitrogen, with crude protein in cow rations at 16% of DM, should be approximately 13-16 mg/100 ml. The predicted MUN level can be calculated for comparison of the obtained data with the studies of other researchers using the formula: MUN (mg/dl) = 0.17 (±0.005)*crude protein (g/kg DM) – 14.2 (±0.849), presented in the studies by J. Nousiainen *et al.* (2004). The predicted level of MUN indicated in Table 4 generally displays lower MUN values than those obtained in the feeding-audit studies, which is most likely associated with regional features of dairy cattle nutrition, namely ration composition and nutritive value, features of metabolic processes in animals of different genotypes, and related factors.

Attention should also be paid to the ratio between fat and protein in milk. Fat and protein indicators in milk should be in a certain relationship with each other. A normal ratio is considered to range from 1.1:1 to 1.5:1. Such a ratio indicates balanced feeding of animals. If the fat-to-protein ratio is above 1.5, this may signal a metabolic disorder in animals. High milk fat content is a sign of intensive mobilisation of fat from body fat depots, while low milk protein content indicates insufficient energy in the ration and in the animal organism. As a result, a metabolic disorder, ketosis, develops in the organism. If such a ratio above 1.5 is observed throughout lactation, it may point to a structurally rich but energy-deficient feeding. It may also indicate low quality of basal feeds and a lack of concentrates. As a result, animals have low productivity and low milk protein content. If the fat-to-protein ratio is lower than 1.1, the ration contains many concentrates and much energy but too few basal feeds rich in structural components, namely fibre.

The results of the comprehensive feeding audit reveal that the key factor in the productivity of a modern dairy herd is not only the ration composition but also the accuracy of its physical implementation. The developed seven-stage audit architecture identifies "bottlenecks" at stages ranging from loading components into the mixer to morphological analysis of animal excreta.

When comparing the developed methodology with publications by international researchers, the concept of A. Bach *et al.* (2007) should be noted. These authors stress that variability in DMI is often caused by the human factor and errors during feed-mixture loading. The obtained data confirm these conclusions. The introduction of control points at the mixing stage stabilised milk yield even without changing the ration composition. However, unlike these researchers, who focus mainly on the technical aspects of mixer operation, the current study expanded the audit to ethological analysis (rumen fill and rumination activity). This provides a more complete picture of the physiological comfort of animals.

The physical structure of the ration is a subject of active debate in modern animal husbandry. The obtained results on the importance of effective fibre (peNDF) and the use of Penn State sieves correlate with studies by B.P. Lammers *et al.* (1996). The researchers state that particle length directly affects rumen pH. However, the results of this study present a different picture in the context of feed separation. It was established that excessive particle length, above 19 mm on the upper sieve, provokes selective eating and eventually leads to subclinical acidosis. In this respect, the position of E.K. Miller-Cushon & M.B. Jensen (2025), according to which feed bunk management, including push-up frequency and uniformity of distribution, is no less important than the theoretical calculation of structure, is fully justified.

Analysis of starch transit deserves particular attention. The results indicate that faecal starch content above 3% is an indicator of considerable financial losses and points to a direct correlation between starch digestibility and energy balance. However, the claims of some researchers, specifically, P. Huhtanen & A.N. Hristov (2009), regarding the exclusive priority of microbial protein synthesis are debatable. The obtained data state that, without proper grain processing (KPS indicator), even an ideal protein balance in the ration does not achieve the target level of feed conversion. The reason for different interpretations may lie in differences in the genetic potential of animals. Under the experimental conditions (high-producing Holsteins), the rate of feed passage is higher, which makes grain-processing quality a critical factor.

The reason for discrepancies in the interpretation of feed efficiency (FE) between the performed studies and literature data may lie in climatic conditions and stress factors. The obtained results record a decrease in FE under heat stress. This requires expansion of the audit programme by including elements such as monitoring of water intake and control of the functioning of cooling systems.

The proposed audit model is a flexible tool that integrates classical zootechnical approaches with modern precision requirements (Precision Dairy Farming). Comparative analysis demonstrates that global research is moving towards a detailed examination of intraruminal processes, and the proposed approach to morphological analysis of manure and assessment of peNDF fully corresponds to these trends. The introduction of this approach enables stable feed conversion of 1.4-1.5 kg of milk per 1 kg of DM, which is an indicator of high competitiveness on the international market.

Conclusions

Within the conducted study, the methodological principles of introducing a feeding-audit protocol as a strategic tool for realising the genetic potential of dairy cattle were examined. The purpose of the study was achieved in full through theoretical justification and practical testing of algorithms for controlling critical points in the system of supplying animals with energy and protein. The limitations of the study included the relatively small sample of farms involved in testing the protocol, which determines the need for further verification of the obtained data on a wider herd with different housing systems.

During the study, a comprehensive analysis of the current state of the feed base and the processes of transforming ration components into products was performed. The physical structure of feed mixtures was assessed using a sieve system, which identified risks of impaired rumen health. Laboratory monitoring of milk urea content and analysis of starch residues in faeces established the conversion level of the main ration components and identified latent energy losses. The efficiency of the transition from general standards of protein feeding to precision balancing of the amino acid profile was evaluated. The results indicated that optimisation of the lysine-to-methionine ratio stabilises milk quality indicators even with moderate crude protein content. A direct dependence was established between the quality of basal-feed preparation and milk output per unit of DM, which is a key marker of the economic stability of a farm.

The obtained results conceptualise feeding audit not simply as a one-off ration check but as a continuous controlled system for managing the biological efficiency of the herd. The scientific value of the work lies in deepening the understanding of relationships between the physical structure of feed, metabolic indicators of nitrogen metabolism, and productive longevity of animals. The developed methodological protocol expands existing approaches to precision livestock farming by transforming complex biochemical patterns into accessible diagnostic markers. The proposed seven-stage monitoring system reduces the influence of the human factor and ensures stability of production processes under industrial conditions.

A promising direction for further research is integrating the developed audit protocol with automated artificial intelligence systems for real-time productivity forecasting and early diagnosis of metabolic disorders.

Acknowledgements

The authors express deep respect and sincere gratitude to the defenders of the Armed Forces of Ukraine, whose courage and resilience enable us to continue scientific work and represent the achievements of Ukrainian science in national and international arenas.

Funding

None.

Conflict of Interest

None.

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Методологічний протокол проведення аудиту годівлі корів як інструмент реалізації генетичного потенціалу тварин

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Анотація. У сучасному промисловому молочному скотарстві повна реалізація генетичного потенціалу тварин залишається складним викликом. На практиці фактична продуктивність часто не відповідає теоретичним розрахункам через технологічні похибки, невраховані чинники середовища та приховані порушення в системі забезпечення тварин поживними речовинами. Це обумовлює необхідність впровадження системного аудиту як інструменту оперативного контролю та корекції виробничих процесів. Мета роботи полягала у теоретичному та методологічному обґрунтуванні комплексного протоколу проведення аудиту системи годівлі для виявлення технологічних розбіжностей, а також у створенні концептуальної моделі для організації експериментальних досліджень та коректної інтерпретації їхніх результатів. Дослідження було засноване на системному підході до оцінки всього ланцюга годівлі. Використано методи порівняльного аналізу, зоотехнічного контролю та інтерпретації біохімічних показників стану організму, зокрема рівня сечовини в молоці. Розроблено детальний алгоритм аудиту, що складається із шести послідовних кроків. На першому етапі проводиться ретельний аналіз поточної ситуації через порівняння розрахункових раціонів із фактичними даними продуктивності та показниками відтворення. Паралельно здійснена оцінка якості кормів, що охоплює аудит умов їхнього зберігання, технологій консервації та вивчення фізико-хімічних властивостей інгредієнтів. Наступний блок зосереджений на операційних процесах приготування та роздавання кормосуміші: контролюється точність завантаження, час змішування та рівномірність розподілу компонентів. Моніторинг споживання передбачав аналіз поведінки тварин, оцінку обсягу залишків та виявлення сепарації часток корму. Заключні етапи включали оцінку фізіологічного стану поголів'я, зокрема кондиції тіла, наповнення рубця та інтенсивності жуйки. Завершувався аудит комплексною інтерпретацією складу молока. Особливу увагу приділено використанню показника сечовини як індикатора ефективності використання білка та енергії, що дозволяє оперативно коригувати годівлю. Впровадження протоколу дозволяє фахівцям ідентифікувати «вузькі місця» у виробничому циклі, знизити витрати кормів на одиницю продукції, попередити розвиток метаболічних порушень та забезпечити максимальну реалізацію біологічних можливостей високопродуктивного стада

Ключові слова: технологічний контроль; сечовина молока; конверсія корму; фізіологічний стан, біологічний потенціал; управлінський алгоритм; якість молочної сировини