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Non-contact assessment of the nutritional value of feed with optical technologies

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Abstract. The nutritional value of feed is assessed with optical instruments using infrared incandescent or halogen lamps as a source of excitation of the spectral signal of the feed. However, no use is still made of energy-efficient diode optics of the visible radiation range. The authors conducted research to identify the possibility of developing a portable feed value analyzer using a spectral analyzer based on diode optoelectronics. First, the Micran-3 infrared microscope was used to study the microstructure of concentrated feed components; then, measurement ranges were selected. The authors studied characteristic ranges of photoluminescence of corn grain, sunflower meal, grain stillage, and rapeseed meal. Excitation (absorption) spectra were measured at synchronous scanning by the SM 2203 spectrofluorimeter monochromators to analyze luminescence spectra of corn silage and concentrated mixed fodder. As a result, integral parameters of spectra were calculated: integral absorption capacity and the photoluminescence flux index. It has been established that the intensity of luminescence spectra of corn silage in the range between 360 and 370 nm and that of concentrated mixed fodder in the range between 420 and 440 nm differ in more than four times. The value of captured photovoltage of corn silage and concentrated mixed fodder differs in six times. The results of optical measurements have proved that the discrepancy of indicators characterizing the nutritional value of feed (dry matter content, total protein content, etc.) has a significant influence on the parameters of optical signals. The authors have proposed the functional design of a portable optical analyzer with diodes, which is capable of estimating the nutritional value of feed by the non-contact method for 12 hours running without additional recharging.

Keywords: non-contact assessment of nutritional value, assessment of nutritional value of feed, luminescence spectra, corn silage, concentrated mixed fodder, spectrum, spectrofluorimeter, light-emitting diode

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ОРИГИНАЛЬНАЯ СТАТЬЯ

Бесконтактная оценка питательной ценности сельскохозяйственных кормов с использованием оптических технологий

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Аннотация. Оценка питательной ценности сельскохозяйственных кормов осуществляется оптическими приборами, в которых в качестве источника возбуждения спектрального сигнала кормов используются инфракрасные лампы накаливания или галогеновые лампы, но энергоэффективная диодная оптика видимого диапазона излучения не применяется. Исследования проведены с целью выявления возможности разработки портативного анализатора питательной ценности кормов с использованием спектрального анализатора на основе диодной оптоэлектроники. Инфракрасным микроскопом Микран-3 исследовали микроструктуру компонентов концентрированного корма и для них подобрали диапазоны измерений. Исследовали характерные диапазоны фотолюминесценции зерна кукурузы, шрота подсолнечного, барды зерновой, шрота рапсового. Измерены спектры возбуждения (поглощения) при синхронном сканировании монохроматорами спектрофлуориметра СМ 2203, и на их основе построены спектры люминесценции кукурузного силоса и концентрированного комбикорма. В результате вычислены интегральные параметры спектров: интегральная поглощательная способность и показатель потока фотолюминесценции. Установлено, что интенсивность спектров люминесценции кукурузного силоса в диапазоне 360…370 нм и концентрированного комбикорма в диапазоне 420…440 нм различается более чем в 4 раза. Величина улавливаемого фотонапряжения кукурузного силоса и концентрированного комбикорма различается в 6 раз. Результаты оптических измерений позволили заключить, что расхождение показателей питательной ценности сельскохозяйственных кормов (содержание сухого вещества, общее содержание протеина и др.) оказывает существенное влияние на параметры оптических сигналов. Предложена функциональная схема портативного оптического анализатора с диодами, способного на протяжении 12 ч без дополнительной подзарядки проводить оценку питательной ценности сельскохозяйственных кормов бесконтактным способом.

Ключевые слова: бесконтактная оценка питательной ценности, оценка питательной ценности сельскохозяйственных кормов, спектры люминесценции, кукурузный силос, концентрированный комбикорм, спектр, спектрофлуориметр, светодиод

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Introduction

Livestock production in Russia remains a priority area in terms of enhancing the country's export opportunities. An important factor of development is the efficient technological activity of enterprises [1].

A large share in the production cost structure of milk and meat includes the costs associated with cattle feeding [2]. Many livestock enterprises directly purchase feed additives, which significantly increases the cost of feeding [3]. In addition to direct costs of feeding, there are indirect costs associated with feed management and efficiency of utilizing feed supplies. The nutritional value of feed is determined by only 25% of Russian livestock enterprises [4]. This is due to the location of most specialized laboratories that determine the nutritional value of feed in the central part of our country, while highly productive livestock enterprises are located mainly in the Vologda and Yaroslavl regions, in the Republics of Tatarstan, Bashkortostan and in Krasnodar Krai [5]. Therefore, the availability of services for analyzing the nutritional value of feed is often associated with high costs, and obtaining the analysis results can take a long time [6]. Therefore, an alternative solution to using the services of specialized laboratories to determine the nutritional value of feed is to employ one's own facilities and devices [7].

We analyzed the advantages and drawbacks of the most common instruments for determining the nutritional value of feed (Table 1). The Analyzer FOSS DS2500 (Denmark) uses the principle of spectral analysis in the near (800 to 1400 nm) and middle infrared (1400 to 2500 nm) ranges [8]. This manufacturer applies optical technologies to determine the nutritional value of plant products without the use of chemical measurements. The company still remains the leader among manufacturers of analytical equipment for agriculture and the processing industry. However, the instrument has a stationary type of design, requires power supply from the central network, and is not designed for use afield [9]. Compact and independent of external power sources are the Dinamica Generalle, X-nir (Italy) and the American Aurora NIR instrument with a touch screen [10].

In addition to the considered solutions, there are other foreign samples of optical analyzers of the nutritional value of feed, but all of them use a similar physical method of operation, and the same type of electronic components [11]. To determine the nutritional value of feed, a portable SCIO Cup feed analyzer has been developed. It is designed in the form of a cup, preventing external illumination during the optical analysis, which determines only the dry matter index in silage, hay, and haylage [12].

The study of existing analytical instruments revealed a tendency of developing portable optical analyzers operating from a battery power source. None of the instruments under consideration use diode optics as a source of excitation of the optical signal [13, 14].

It is necessary to consider the prospects of using energy-efficient diode optics of the visible radiation range (200 to 800 nm) in instruments measuring the nutritional value of feed.

The research purpose: revealing the possibility of developing a portable analyzer of the nutritional value of feed using a spectral analyzer based on diode optoelectronics.

Materials and methods

We have carried out a comparative analysis of the functionality of existing instruments determining the nutritional value of feed. Characteristic ranges of photoluminescence of common feed types were determined for corn grain, sunflower meal, grain stillage, and rapeseed meal.

Studies of optical properties were carried out on the SM 2203 spectrofluorimeter, which can determine the excitation, emission, polarization, quantum yield, and the absorption spectra of liquid and solid samples of feed [15].

We took as study samples corn silage with a moisture content of 70% and components of concentrated mixed fodder consisting of corn grain, sunflower meal, grain stillage, and rapeseed meal with a moisture content of 14% and used as an additive in cattle diets.

Optical measurements of corn grain, grain stillage, and rapeseed meal were carried out (Fig. 1). The detailed study of the microstructure of concentrated feed components facilitated the task of further selection of the measurement range to determine their nutritional value.

The peculiarity of measurements was that the total protein content per fraction of dry matter in corn silage and sunflower meal differs in more than two times,

Table 1

Instruments for determining the nutritional value of feed Using with infrared spectroscopy

Таблица 1

Приборы для определения питательной ценности сельскохозяйственных кормов, использующие для измерений инфракрасную спектроскопию

Analyzer, purpose, manufacturer		Advantages	Drawbacks
FOSS DS2500, stationary, Denmark		Determines fat content, protein content, dry matter, moisture content, ash content and total fiber content and total fiber content	Requires regular maintenance, pre-calibration
Dinamica Generalle, X-nir, portable, Italy		Divides the total fiber content into ADF and NDF, determines starch content. Compact, with a removable battery	Not suitable for use in winter, requires pre-warming of the device during operation
Aurora NIR, portable, USA		Large touch screen display, compact, shows the spectral curve	Uses energy-consuming incandescent lamps
SCIO Cup feed analyzer, portable, Israel		Prevents external light during the optical analysis, mobile app	Determines the value of dry matter only

and this can have a significant impact on the difference of optical properties of each sample.

For the spectrum of wave numbers in the absorption regions of carbohydrates, fats, and proteins, the integral absorption coefficients A_k in the spectral interval k_1-k_2 were determined [16]:

$$A_k = \int_{k_1}^{k_2} \alpha(\lambda)\, dk, \qquad (1)$$

where α(λ) is the spectral absorption characteristic; k_1, k_2 are the boundaries of the frequency spectral range.

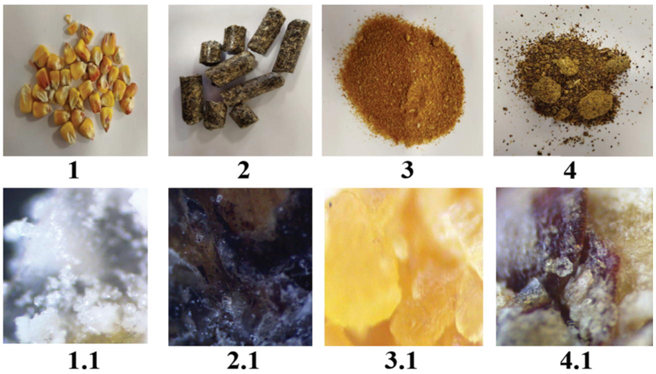

Fig. 1. Components of concentrated mixed fodder and the microstructure of corresponding samples (×20), obtained with the infrared microscope Mikran-3:
1 – corn grain; 2 – sunflower meal;
3 – grain stillage; 4 – rapeseed meal

Рис. 1. Компоненты концентрированного комбикорма и микроструктура соответствующих образцов (×20), полученная с помощью инфракрасного микроскопа Микран-3:
1 – зерно кукурузы; 2 – шрот подсолнечный;
3 – барда зерновая; 4 – шрот рапсовый

The results of the conducted studies to determine the nutritional value of feed components are presented in Table 2.

It follows from the data of Table 2 that beet pulp absorbs more actively than other components in the range between 800 and 1170 cm^{-1}. For rapeseed meal, on the contrary, absorption is higher in the range between 1260 and 1410 cm^{-1}, where Ak differs from other components in 1.15 to 1.73 times. For corn stillage and ground corn, the absorbance rate is approximately the same for each range. In the "protein" and "fat" regions the absorption rate is significantly lower and the difference in absolute values is less noticeable. Rapeseed meal was found to have the highest absorption rate.

First, we measured the excitation characteristics η(λ) in the range between 230 and 600 nm according to the previously developed technique [16]. Based on the obtained results, we measured the photoluminescence spectra φ(λ). From the obtained spectral characteristics, the integral absorption capacity H was calculated from the formula:

$$H = \int_{\lambda_1}^{\lambda_2} \eta(\lambda)\, d\lambda, \qquad (2)$$

where η(λ) is the spectral characteristic of excitation; λ_1, λ_2 are the boundaries of the spectral range of excitation.

Integral parameters of the spectra φ(λ) – photoluminescence fluxes Φ – were determined from the formula:

$$\Phi = \int_{\lambda_1}^{\lambda_2} \varphi(\lambda)\, d\lambda, \qquad (3)$$

where φ(λ) where φ(λ) is the spectral characteristic of photoluminescence; λ_1, λ_2 are the boundaries of the photoluminescence spectral range.

Table 2

Integral coefficients A_k in absorption regions (k_1-k_2)

Таблица 2

Интегральные коэффициенты A_k в областях поглощения (k_1-k_2)

Measurement range, nm	Integral absorption coefficient, A_k, %				
	Beet pulp	Corn stillage	Ground corn	Rapeseed meal	Concentrated mixed fodder
Carbohydrates					
800 to 920	1.08	1.07	1.03	0.91	-
1030 to 1125	1.58	1.47	1.37	1.15	-
1060 to 1150	1.42	1.33	1.27	1.05	-
1075 to 1100	0.46	0.42	0.40	0.33	-
1100 to 1170	1.01	0.97	0.92	0.77	-
1260 to 1350	0.22	0.21	0.26	0.36	-
1310 to 1410	0.23	0.22	0.30	0.38	-
Proteins and fats					
1300 to 1400	0.27	0.33	0.43	0.47	0.28
1550 to 1650	0.43	0.36	0.37	0.36	0.33
1485 to 1550	0.45	0.46	0.56	0.54	0.38
1610 to 1660	0.25	0.24	0.14	0.48	0.35
3030 to 3130	0.28	0.32	0.31	0.30	0.29

All measurements were taken in a 20-fold repetition, so that the error in determining the integral parameters H and Φ did not exceed 10% at a confidence level of 0.9.

As a result of measurements, curves characterizing optical properties of corn silage and concentrated mixed fodder were obtained. The results were statistically processed and averaged over 20 measurements.

Results and discussion

As a study result for corn silage and concentrated mixed fodder, the excitation (absorption) spectra $\eta_e(\lambda)$ were measured with spectrofluorimeter monochromators at synchronous scanning, and luminescence spectra $\varphi(\lambda)$ were determined then.

The integral parameters of the spectra were calculated in the R computing environment. During the measurements, the optical excitation was changed under the influence of the varying moisture level of corn silage from 75 to 55% with a step of 1% determined by a gravimetric moisture meter. As a result of measurements and statistical processing of optical data for corn silage, the photoluminescence spectrum η averaged over 20 measurements was obtained and expressed in relative units (r.u.). It was revealed that the greatest signal fluctuation is observed in the range between 300 and 400 nm (Fig. 2).

The optical properties of concentrated mixed feed consisting of corn grain, sunflower meal, grain stillage, and rapeseed meal had greater absorption intensity of the optical signal. The peaks of the plots shifted in the range between 400 and 520 nm (Fig. 3).

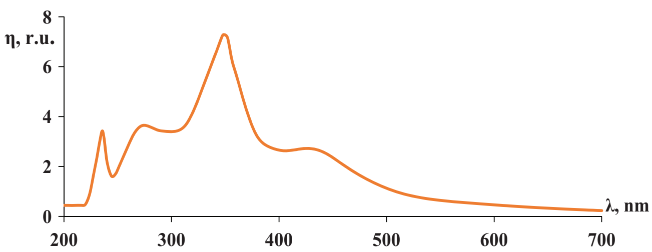

Fig. 2. Photoluminescence spectrum of corn silage

Рис. 2. Спектр фотолюминесценции кукурузного силоса

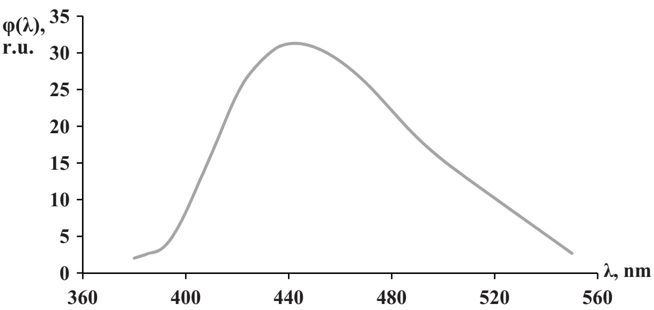

Fig. 3. Averaged photoluminescence spectrum of concentrated mixed fodder

Рис. 3. Усредненный спектр фотолюминесценции концентрированных кормов

Estimating the intensity of the luminescence spectra of corn silage and concentrated mixed fodder consisting of corn grain, sunflower meal, grain stillage, and rapeseed meal (Fig. 2, 3), which differed in more than four times, we can hypothesize about the influence of chlorophyll contained in greater amounts in corn silage, which absorbs the optical flux of the radiation source and thus contributes to the decrease in the spectrum intensity. However, the photoluminescence spectrum of concentrated mixed fodder (Fig. 3) is also characterized by the intensity peculiar to plant protein groups, confirming the fact of higher protein content in the analyzed sample (in more than six times).

In accordance with the obtained results, we can state that the indicators of the nutritional value of feed (dry matter content and total protein content) can be determined by the optical method using photodiodes for photoluminescence registration and LEDs for its excitation [16].

The functional diagram of the proposed portable optical analyzer of the nutritional value of feed based on the diode component base is shown in Figure 4.

According to the proposed functional diagram, it is possible to produce an energy-efficient portable analyzer with diodes serving as luminescence excitation sources. The diodes will ensure continuous operation of the device for 12 h (during a working shift) without additional recharging from a commercially available battery with a voltage of 18 V and a capacity of 2 Ah.

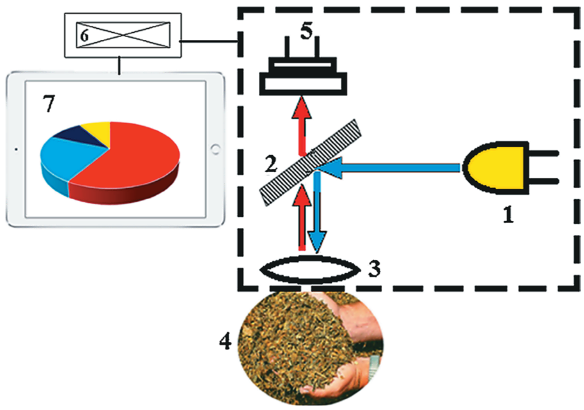

Fig. 4. Functional diagram of the technological process of analyzing the nutritional value of feed with the spectral analyzer:
1 – LED source; 2 – dielectric mirror; 3 – condenser; 4 – feed; 5 – photodiode block; 6 – controller with interface device; 7 – instrument display or mobile application

Рис. 4. Функциональная схема технологического процесса анализа питательной ценности с использованием спектрального анализатора:
1 – светодиодный источник; 2 – диэлектрическое зеркало; 3 – конденсор; 4 – корм; 5 – блок фотодиодов; 6 – контроллер с устройством сопряжения; 7 – дисплей прибора или мобильное приложение

The expected technological effect of the proposed solution is the reduction of time costs associated with the chemical analysis of the nutritional value of feed, as well as the possibility of adjusting the diet of animals kept on the livestock farm.

Further research will focus on the development and manufacture of a prototype of a portable express analyzer of the nutritional value of feed and the development of optical calibrations.

Conclusions

1. The existing optical instruments for determining the nutritional value of feed use infrared incandescent lamps or halogen lamps of special purpose as a source of excitation of the spectral signal. The lamps take measurements in the near or middle infrared range.

2. Research results confirm the possibility of using LEDs in the ranges between 200 to 800 nm and 800 to 1400 nm.

3. Some indicators of the nutritional value of feed, such as dry matter content and total protein content, can be determined by the optical method using photodiodes for photoluminescence registration and LEDs for its excitation. The greatest variation in the optical properties of feed is observed in the visible radiation range.

4. According to the proposed functional diagram, it is possible to produce a prototype of an optical device for the express assessment of the nutritional value of feed.

References

1. Kirsanov V.V. Structural and functional models for building new generation automated and robotic dairy farms. *Agricultural Machinery and Technologies*. 2022;16;1:4-9. (In Russ.) https://doi.org/10.22314/2073-7599-2022-16-1-4-9

2. Mikhailichenko S.M., Kupreenko A.I., Ivanov Yu.G., Nikitin E.A. Optimization of volume for an automatic feed wagon by graph theory based modeling. *Agricultural Machinery and Technologies*. 2023;17;4:35-41. (In Russ.) https://doi.org/10.22314/2073-7599-2023-17-4-35-41

3. Erokhin M.N., Dorokhov A.S., Kirsanov V.V., Chepurina E.L. Conceptual grounds for the construction of a regional multifunctional service center for dairy livestock. *Agricultural Engineering* (*Moscow*). 2021;1(101):4-10. (In Russ.) https://doi.org/10.26897/2687-1149-2021-1-4-10

4. Ivanov Yu.G., Mashoshina E.V., Verlikova L.N., Gabdullin G.G., Lukyanchuk E.V., Verlikov V.V. Robotic technology of obtaining milk from individual cows and its technical and economic evaluation. *Machinery and technologies in livestock.* 2021;2(42):46-52. (In Russ.)

5. Kupreenko A.I., Isaev Kh.M., Mikhailichenko S.M. Automatic cattle feeding system based on the use of a suspended robotic feeder. *Machinery and technologies in livestock.* 2021;3(43):5-9. (In Russ.)

6. Lyalin E.A., Trutnev M.A.; Trutnev N.V. Parameters of the spiral-screw device for dosing mineral fertilizers with different consumption characteristics. *Perm Agrarian Journal.* 2021;4(36):14-22. (In Russ.) https://doi.org/10.47737/2307-2873_2021_36_14

7. Lyalin E.A.; Trutnev M.A.; Trutnev N.V. Performance assessment of mixed fodder distributor with a spiral-screw dispenser. *Perm Agrarian Journal.* 2019;4(28):4-10. (In Russ.)

8. Simachkova M.S. Analysis of technological lines and equipment for the preparation of compound feeds. *Bulletin NGIEI*. 2023;6(145):18-36. (In Russ.)

9. Vakhrushev A.V., Zemskov A.V., Fedotov A.Yu. Hardware-software complex for uniform mixing analysis of micro and nanoelements. *Chemical Physics and Mesoscopy.* 2009;11;4:421-429. (In Russ.)

10. Nikitin E.A., Semenyuk V.S. Analysis of feed mixture effective preparation's problems in the modern farming. *Vestnik Vserossiyskogo Nauchno-Issledovatelskogo Instituta Mekhanizatsii Zhivotnovodstva*. 2019;2(34):158-163. (In Russ.)

11. Bloch V., Levit H., Halachmi I. Assessing the potential of photogrammetry to monitor feed intake of dairy cows. *Journal of Dairy Research*. 2019;86(1):34-39. https://doi.org/10.1017/S0022029918000882

Список источников

1. Кирсанов В.В. Структурно-функциональные модели построения автоматизированных и роботизированных молочных ферм нового поколения // Сельскохозяйственные машины и технологии. 2022. Т. 16, № 1. С. 4-9. https://doi.org/10.22314/2073-7599-2022-16-1-4-9

2. Михайличенко С.М., Купреенко А.И., Иванов Ю.Г., Никитин Е.А. Оптимизация объема роботизированного кормораздатчика методом моделирования с применением теории графов // Сельскохозяйственные машины и технологии. 2023. Т. 17, № 4. С. 35-41. https://doi.org/10.22314/2073-7599-2023-17-4-35-41

3. Ерохин М.Н., Дорохов А.С., Кирсанов В.В., Чепурина Е.Л. Концепция построения регионального многофункционального сервисного центра по молочному животноводству // Агроинженерия. 2021. № 1 (101). С. 4-10. https://doi.org/10.26897/2687-1149-2021-1-4-10

4. Иванов Ю.Г., Машошина Е.В., Верликова Л.Н., Габдуллин Г.Г., Лукьянчук Е.В., Верликов В.В. Роботизированная технология получения молока от отдельных коров и ее технико-экономическая оценка // Техника и технологии в животноводстве. 2021. № 2 (42). С. 46-52. EDN: DOXBLH

5. Купреенко А.И., Исаев Х.М., Михайличенко С.М. Автоматическая система кормления КРС на базе подвесного роботизированного кормораздатчика // Техника и технологии в животноводстве. 2021. № 3 (43). С. 5-9. EDN: GURWWY

6. Лялин Е.А., Трутнев М.А., Трутнев Н.В. Параметры спирально-винтового устройства для дозирования минеральных удобрений с различными расходными характеристиками // Пермский аграрный вестник. 2021. № 4 (36). С. 14-22. https://doi.org/10.47737/2307-2873_2021_36_14

7. Лялин Е.А., Трутнев М.А., Трутнев Н.В. Оценка эффективности работы раздатчика комбикормов со спирально-винтовым дозатором в производственных условиях // Пермский аграрный вестник. 2019. № 4 (28). С. 4-10. EDN: ZOFCES

8. Симачкова М.С. Анализ технологических линий и оборудования для приготовления комбикормов // Вестник НГИЭИ. 2023. № 6 (145). С. 18-36. EDN: IXKLBI

9. Вахрушев А.В., Земсков А.В., Федотов А.Ю. Программно-аппаратный комплекс для анализа равномерности перемешивания микро- и наноэлементов // Химическая физика и мезоскопия. 2009. Т. 11, № 4. С. 421-429. EDN: PJLTGJ

10. Никитин Е.А., Семенюк В.С. Анализ проблем эффективного приготовления кормовой смеси в современном животноводстве // Вестник Всероссийского научно-исследовательского института механизации животноводства. 2019. № 2 (34). С. 158-163. EDN: KJPYIL

12. Lednev V.N., Sdvizhenskii P.A., Grishin M.Y., Gudkov S.V., Pershin S.M., Nikitin E.A. Improving calibration strategy for LIBS heavy metals analysis in agriculture applications. *Photonics*. 2021;8(12):563. https://doi.org/10.3390/photonics8120563

13. Knight C.H. Quality dairying. *Journal of Dairy Research*. 2023;90(3):215-220. https://doi.org/10.1017/S0022029923000535

14. Ichimura T., Kusaka M., Nakamura T. The effect of high-temperature heat treatment and homogenization on the microstructure of set yogurt curd networks. *Journal of Dairy Research.* 2023;90(3):306-311. https://doi.org/10.1017/S0022029923000523

15. Varkhushev A.V. Modeling the processes of ordering and self-organization of nanostructures. *Chemical Physics and Mesoscopy*. 2005;7;2:219-228. (In Russ.)

16. Belyakov M.V., Pavkin D.Yu., Nikitin E.A., Efremenkov I.Yu. Substantiation of the choice of special ranges for photoluminescent control of the composition and nutritional value of forages. *Machinery and Equipment for Rural Area*. 2023;2(308):31-36. (In Russ.)

11. Bloch V., Levit H., Halachmi I. Assessing the potential of photogrammetry to monitor feed intake of dairy cows. Journal of Dairy Research. 2019;86(1):34-39. https://doi.org/10.1017/S0022029918000882

12. Lednev V.N., Sdvizhenskii P.A., Grishin M.Y., Gudkov S.V., Pershin S.M., Nikitin E.A. Improving calibration strategy for LIBS heavy metals analysis in agriculture applications. Photonics. 2021;8(12):563. https://doi.org/10.3390/photonics8120563

13. Knight C.H. Quality dairying. Journal of Dairy Research. 2023;90(3):215-220. https://doi.org/10.1017/S0022029923000535

14. Ichimura T., Kusaka M., Nakamura T. The effect of high-temperature heat treatment and homogenization on the microstructure of set yogurt curd networks. Journal of Dairy Research. 2023;90(3):306-311. https://doi.org/10.1017/S0022029923000523

15. Вархушев А.В. Моделирование процессов упорядочения и самоорганизации наноструктур // Химическая физика и мезоскопия. 2005. Т. 7, № 2. С. 219-228. EDN: PJRNPP

16. Беляков М.В., Павкин Д.Ю., Никитин Е.А., Ефременков И.Ю. Обоснование выбора спектральных диапазонов фотолюминесцентного контроля состава и питательной ценности кормов // Техника и оборудование для села. 2023. № 2 (308). С. 31-36. EDN: ZMQMNG

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D.A. Blagov – analytics, investigation and discussion;
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