УДК 636.597.034/619

Research article

Open access

DOI: 10.32634/0869-8155-2025-392-03-110-115

Correlation dependence between feed moisture and its optical properties using sunflower cake as an example

Dmitry A. Blagov ✉
Evgeny A. Nikitin
Mikhail V. Belyakov

Federal Scientific Agroengineering Center VIM

✉ *aspirantyra2013@gmail.com*

Received by the editorial office: 24.10.2024
Accepted in revised: 13.02.2025
Accepted for publication: 27.02.2025

ABSTRACT

Each type of agricultural feed has unique optical properties and nutritional value characteristics that must be taken into account at the stage of drawing up an animal feeding diet to ensure the rational management of economic processes at industrial livestock enterprises.
Arbitrage chemical methods for assessing the moisture content and nutritional value of agricultural feed are laborious in the implementation. World practice shows that optical methods can serve as an effective alternative for the development and manufacture of a new generation instrument base that allows determining the qualitative properties of materials, including agricultural feed (nutritional value).
The most time-consuming procedure for developing optical devices is to obtain optical calibrations (see definition), which provide interpretation of the values of an indirect parameter that characterizes the nutritional value of agricultural feed.
The study describes the process of obtaining optical calibrations by varying the control indicator (using the example of feed moisture), followed by building a correlation between the value of an indirect parameter (photoluminescence intensity) and the control indicator. Including in a portable express analyzer operating on the basis of photoluminescence.
The proposed method of forming a control indicator can be used to obtain optical calibrations for rapid determination of total fat content and other indicators of nutritional value.

Key words: photoluminescent control, rapid determination of humidity, detection of nutritional value

For citation: Blagov D.A., Nikitin E.A., Belyakov M.V. Correlation dependence between feed moisture and its optical properties using sunflower cake as an example. *Agrarian science.* 2025; 392(03): 110–115.
https://doi.org/10.32634/0869-8155-2025-392-03-110-115

Научная статья

Открытый доступ

DOI: 10.32634/0869-8155-2025-392-03-110-115

Корреляционная зависимость между влажностью корма и его оптическими свойствами на примере жмыха подсолнечника

Д.А. Благов ✉
Е.А. Никитин
М.В. Беляков

Федеральный научный агроинженерный центр ВИМ, Москва Россия

✉ *aspirantyra2013@gmail.com*

Поступила в редакцию: 24.10.2024
Одобрена после рецензирования: 13.02.2025
Принята к публикации: 27.02.2025

РЕЗЮМЕ

Каждый тип сельскохозяйственного корма имеет уникальные оптические свойства и характеристики питательной ценности, которые необходимо учитывать на этапе составления рациона кормления животных для обеспечения рационального ведения хозяйственных процессов на промышленных животноводческих предприятиях.
Арбитражные химические методы оценки содержания влажности и питательной ценности сельскохозяйственных кормов трудоемки в реализации. Мировая практика показывает, что оптические методы могут служить эффективной альтернативой для разработки и изготовления приборной базы нового поколения, позволяющей определять качественные свойства материалов, в том числе сельскохозяйственных кормов (питательную ценность).
Наиболее трудоемкая процедура разработки оптических приборов — это получение оптических калибровок (см. определение), которые обеспечивают интерпретацию значений косвенного параметра, характеризующего питательную ценность сельскохозяйственных кормов.
Исследование описывает процесс получения оптических калибровок методом варьирования контрольного показателя (на примере влажности корма) с последующим построением корреляционной связи между значением косвенного параметра (интенсивности фотолюминесценции) и контрольного показателя. Формирует методику построения алгоритмической связи для определения питательной ценности сельскохозяйственного корма. В том числе в портативном экспресс-анализаторе, функционирующем на основе фотолюминесценции.
Предлагаемая методика варьирования контрольного показателя может быть применена для получения оптических калибровок для экспресс-определения общего содержания жира и других показателей питательной ценности.

Ключевые слова: фотолюминесцентный контроль, экспресс-определение влажности, детектирование питательной ценности

Для цитирования: Благов Д.А., Никитин Е.А., Беляков М.В. Корреляционная зависимость между влажностью корма и его оптическими свойствами на примере жмыха подсолнечника. *Аграрная наука*. 2025; 392(03): 110–115 (in English).
https://doi.org/10.32634/0869-8155-2025-392-03-110-115

Introduction

With the advent of automated data processing tools and specialized software for generating machine learning models, a number of technologies that previously had high cost have become more accessible. This can include image recognition tools (unlocking the phone screen, paying using biometrics, etc.), crop yield forecasting tools using aerial photography, and others.

The basis for the implementation of such solutions is formed by two components: the perfection of the hardware for detecting signs and the efficiency of their processing algorithms [1].

Speaking about the hardware, it is worth noting the importance of modern methods of manufacturing photosensitive electronic components using photolithography. For example, the camera of a modern phone is generally a crystal (matrix) with an area of up to 0.00005 m^2, on which up to 10 million pixels can be located, each of which is an independent photodiode generating micro voltages of different values depending on depends on the intensity of the recorded radiation. Such hardware solutions generate a stream of big data, the processing of which makes it possible to develop solutions useful for modern humans.

In turn, the effectiveness of algorithms for processing output data is determined not only by the reliability of correlation dependencies, but also by an understanding of the fundamental physical processes that take place in the objects of research [2, 3].

An established innovation trend of the last decade

In the agricultural sector, they consider the development of intelligent diagnostic tools for agricultural products, non-destructive testing tools and yield forecasting tools [4].

Most of the input data for the solutions described above is collected using optical devices and photosensitive sensors. This is confirmed by the results of a study by R.M. Buelvas *et al.*, devoted to the description of the process of assessing the biomass of leafy vegetables based on ultrasonic and optical sensors [5].

In addition, optical devices that carry out luminescent control make it possible to assess the temperature of the canopy surface in artificial crop cultivation systems and control the microclimate [6]. By complementing the simplest tools for scanning luminescence characteristics with machine learning algorithms, oxygen concentration and temperature can be predicted, based on a single measurement [7].

At the same time, the photoluminescent method of detecting biological objects can provide end-to-end quality control of cultivated agricultural products for maximum permissible concentrations of undesirable acids [8], assess the moisture level during the cultivation of cereals [9], determine the effectiveness of seed disinfection with a fungicide against fusarium [10, 11] and identify bacteria provoking fusarium in products at an early-stage crop production [12, 13].

With the development of the optoelectronic industry and the possibility of manufacturing nano-probes, photoluminescence is used for invasive assessment of the quality of transported products in large volumes, the result of the study was demonstrated by Chinese scientists using the example of chicken meat evaluation [14, 15]. Electronic components that perceive a photo signal have also found their application in the field of industry for diagnosing the efficiency of technical liquids, this makes it possible to regulate the replacement of appropriate substances taking into account the actual lubricating and cooling properties, thereby preventing premature failure of machinery and equipment [16, 17]. More advanced sensors using intelligent algorithms provide segmentation of images of various substances and predict their properties using tools for processing the obtained parameters using fuzzy logic methods [18, 19].

Using regression models for processing spectral parameters of photoluminescence and milk fat, it is possible to detect falsification of butter with a simple hardware complex [20].

Speaking about feeding the animals themselves, the importance of analyzing the nutritional value of agricultural feed at the stage of ration preparation and direct preparation is no less important than the control of the products obtained. The quality of animal feeding and sufficient energy production definitely affects both the health of cattle and the quality of the products obtained, which has been repeatedly justified by world-renowned scientists [21], however, among existing scientific papers, the process of obtaining calibrations and algorithms that serve as a tool for interpreting indirect photoluminescence parameters describing changes in the nutritional value of agricultural feed is not clearly disclosed.

This study will be devoted to describing the process of obtaining optical calibrations (see definition) for express determination of the nutritional value of agricultural feed by non-contact methods using diodes that generate a reflected photoluminescence flux and photosensitive sensors to register the values of the corresponding flux.

The purpose of the study is to describe the process of establishing a correlation between the moisture content of the feed and its optical properties.

The object of research — sunflower cake, used as a protein concentrated feed additive in animal husbandry.

Materials and methods

In cattle feeding, the key indicator determining the amount of nutrients received into the animal's body is the dry matter content — this is the inverse of the moisture content of the feed. Detecting this indicator by optical methods is more time-efficient than using the arbitration method.

The research suggests a technique for obtaining calibrations, presented in the form of calibration curves and mathematical models that describe the relationship between the optical properties of the feed and the value of the control indicator (as an example, we varied the humidity level / dry matter content.

1) Detection of optical properties

Optical properties were detected by spectral fluorescence measurements on a spectrofluorimeter CM2203 (manufactured by SOLAR, Republic of Belarus), with specialized software. An external light-shielding camera connected by a fiber-optic cable was developed to measure solid samples.

The spectral characteristics of excitation (absorption) n (λ) were measured in the range from 250–600 nm. The repeatability of measurements is tenfold. To measure the luminescence spectrum φ (λ), the excitation monochromator was set to the same wavelength at which the maximum of the excitation spectrum is observed during synchronous scanning. All spectra were adjusted for instrumental excitation distortions using the built-in software of the measuring device.

The calculation of the integral parameters of the excitation and luminescence spectra was carried out according to the formulas:

$$H=\int_{\lambda_2}^{\lambda_1}\eta(\lambda)d\lambda \quad (1),$$

$$\Phi=\int_{\lambda_2}^{\lambda_1}\varphi(\lambda)d\lambda \quad (2),$$

where n (λ) is the spectral characteristic of excitation (absorption), φ (λ) is the spectral characteristic of photoluminescence, λ1...λ2 are the boundaries of spectral ranges.

2) *Variation of the value of the control indicator (humidity / dry matter content), using the example of sunflower cake*

In the presented example, a moisture meter with analytical scales (CAS, Japan) was used to determine the basic mass index of the test sample and to verify the change in humidity by the gravimetric method according to the presented scheme (Fig. 1).

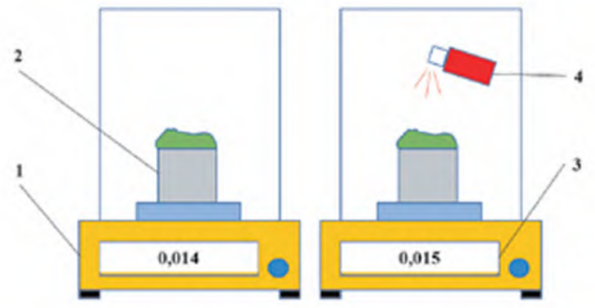
The control indicator (dry matter content / humidity level) was varied in two directions (increase and decrease).

Humidity was increased by irrigating the test sample from a laboratory pulverizer in 1% increments and hermetically storing the sample for 24 hours, humidity was reduced by drying the sample on a moisture meter with analytical scales. The variable range of humidity levels ranged from 8.2 to 19.1%.

Optical measurements for each sample of concentrated feed were carried out with 10-fold repetition at each step of humidity variation.

Next, statistical data processing was carried out and correlations of optical properties and moisture content in concentrated feed were obtained. The flow dependencies were approximated, depending on the indicators of the variable flow.

Fig. 1. Description of the process of varying the dry matter content in concentrated feed: 1 — analytical scales, 2 — hermetic bux for the measured sample, 3 — a tableau displaying the mass of the sample, 4 — a means of irrigating the samples



The presented method of varying the control indicator can be applied to other values. For example, the construction of a correlation between the total fat content in the feed and the value of an indirect parameter (photoluminescence intensity) is carried out using a similar method of varying the total fat content up.

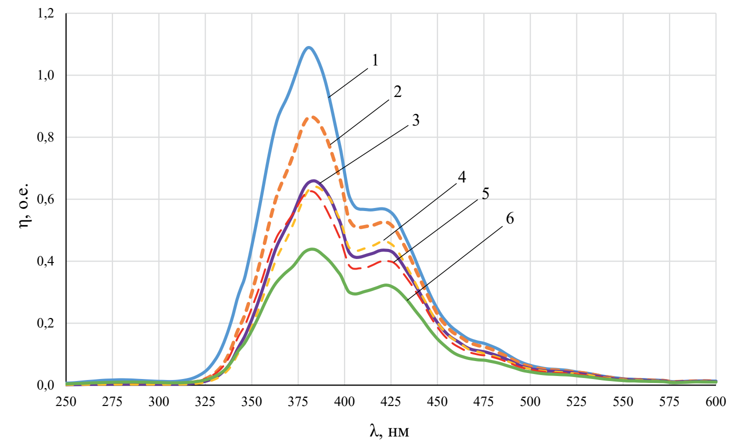
Results and discussion

As a result of carrying out multiple measurements using the above-described technique, spectral excitation characteristics n (λ) of a concentrated feed additive (sunflower cake) with different humidity levels (dry matter content) were obtained. This was obtained by synchronous scanning of samples.

After that, the set of obtained data was subjected to statistical processing, thanks to which graphs were obtained characterizing the dependences of the excitation spectra of sunflower cake and its humidity (Fig. 2).

Graphical representation of the results of the study demonstrates that all spectral characteristics have a qualitatively similar appearance, but with increasing humidity they shift downwards. This is caused by the extinguishing of luminescence.

Fig. 2. Synchronous excitation spectra of sunflower cake of different humidity: humidity of the sample for curve 1 — 8.2%; humidity of the sample for curve 2 — 10.3%; humidity of the sample for curve 3 — 13.0%; humidity of the sample for curve 4 — 14.7%; humidity of the sample for curve 5 — 16.3%; humidity of the sample for curve 6 — 19.1%



The main maximum of the spectra is at a wavelength of 382 nm, the other, less pronounced, at 424 nm. The ratio of these maxima decreases with increasing humidity.

The obtained results of measuring the excitation spectra provided detection of photoluminescence spectra φ (λ). An example for the excitation wavelength of 382 nm is shown in Figure 3.

The tendency of the spectra to shift downwards with increasing humidity naturally persists for photo-luminescence spectra. This was revealed when determining the integral photoluminescence fluxes for excitation wavelengths of 382 nm 424 nm in the spectral ranges 430–600 nm and 490–640 nm, respectively. The corresponding results are shown in Table 1.

An example of the correlation dependencies of the integral photoluminescence fluxes Φ and hu-midity of concentrated feed samples (sunflower cake), with a linear appro-ximation, is shown in Figure 4.

The linear approximation is statistically reliable, since the coef-ficients of determination R^2 for the dependence Φ382 nm (W) are 0.94 and for the dependence Φ424 nm (W) — 0.96. From the point of view of practical implementation, the use of 382 nm excitation is of greater interest due to the significantly larger magnitude of the photo signal.

Fig. 3. Luminescence spectra of sunflower cake at an excitation wavelength of 382 nm for samples of different humidity: sample humidity for curve 1 is 8.2%; sample humidity for curve 2 is 10.3%; sample humidity for curve 3 is 14.7%; sample humidity for curve 4 is 13.0%; the humidity of the sample for curve 5 is 16.3%; the humidity of the sample for curve 6 is 19.1%

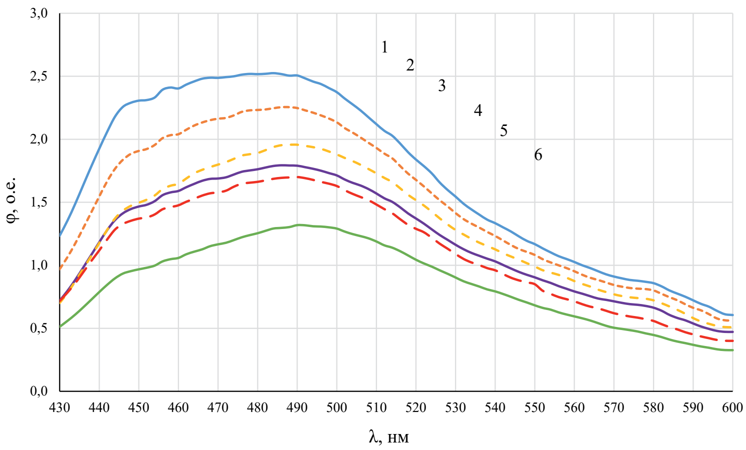
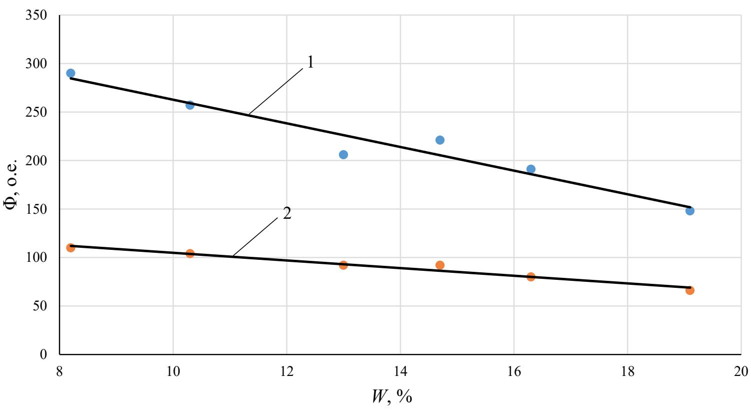


Fig. 4. Dependence of luminescence fluxes on the moisture content of sunflower cake; 1 — the excitation wavelength of 382 nm; 2 — the excitation wavelength of 424 nm



The results obtained demonstrate the process of obtaining calibration curves that characterize the content of the substance of interest in the analyzed material, contain a description of the methodology for varying the moisture content of samples and processing the recorded indicators to build correlation dependencies.

The inverse characteristics of W(Φ) are calibration models for processing a photovoltaic signal to ensure the operation of a specialized photoluminescent device for determining humidity and other indicators of the nutritional value of agricultural feed.

The number of indicators to be determined and the types of feed to be analyzed are determined by the number of calibration models developed according to the presented methodology.

Table 1. **Integral parameters of excitation spectra and photoluminescence spectra of sunflower cake**

Humidity *W*, %	H ± ΔH, Relative units	Φ ± ΔΦ, Relative units	
	230–600 nm	382 nm	424 nm
8.2	84 ± 6	290 ± 16	110 ± 7
10.3	69 ± 4	257 ± 11	104 ± 5
13.0	55 ± 3	206 ± 11	92 ± 5
14.7	54 ± 2	221 ± 10	92 ± 7
16.3	53 ± 3	191 ± 11	80 ± 10
19.1	40 ± 3	148 ± 11	66 ± 5

Conclusions

This study is description of the process of obtaining optical calibrations that characterize the dependence of the control indicator (moisture / dry matter content) in sunflower cake and can be used in the development of a portable device for rapid determination of the nutritional value of agricultural feed by non-contact methods using diodes that generate a reflected photoluminescence flux and photosensitive sensors that register indirect parameters nutritional value.

Using the example of sunflower cake, synchronous excitation spectra were recorded and the dependences of luminescence fluxes for samples of different humidity levels were determined, while the coefficient of determination R^2 for the dependence of Φ382 nm (W) was 0.94 and for the dependence of Φ424 nm (W) — 0.96.

The results of the studies can be scaled by using the described methods for obtaining regression models that characterize the relationship between the optical signal and other indicators of the nutritional value of the feed.

REFERENCES

1. Kirsanov V.V., Belyakov M.V., Nikitin E.A., Blagov D.A., Mikhailichenko S.M. Spectral analysis as a tool for determining the mixing quality of a multicomponent feed mixture. *Vestnik Bashkir State Agrarian University*. 2023; (3): 41–46 (in Russian). https://www.elibrary.ru/rcobbx

2. Pavkin D.Y., Belyakov M.V., Nikitin E.A., Efremenkov I.Y., Golyshkov I.A. Determination of the Dependences of the Nutritional Value of Corn Silage and Photoluminescent Properties. *Applied Sciences.* 2023; 18(13): 10444. https://doi.org/10.3390/app131810444

3. Morozov N.M., Kirsanov V.V., Tsench Yu.S. Historical and Analytical Assessment of Automation and Robotization for Milking Processes. *Agricultural Machinery and Technologies*. 2023; 17(1): 11–18 (in Russian). https://doi.org/10.22314/2073-7599-2023-17-1-11-18

4. Dorokhov A.S., Kirsanov V.V., Pavkin D.Yu., Nikitin E.A., Mikhailichenko S.M., Blagov D.A. Analysis of robotic feeders for livestock complexes for the cattle breeding. *Electrical technology and equipment in the agro-industrial complex*. 2023; 70(1): 94–104 (in Russian). https://doi.org/10.22314/2658-4859-2023-70-1-94-104

5. Buelvas R.M., Adamchuk V.I., Leksono E., Tikasz P., Lefsrud M., Holoszkiewicz J. Biomass estimation from canopy measurements for leafy vegetables based on ultrasonic and laser sensors. *Computers and Electronics in Agriculture*. 2019; 164: 104896. https://doi.org/10.1016/j.compag.2019.104896

6. Giménez-Gallego J., González-Teruel J.D., Soto-Valles F., Jiménez-Buendía M., Navarro-Hellín H., Torres-Sánchez R. Intelligent thermal image-based sensor for affordable measurement of crop canopy temperature. *Computers and Electronics in Agriculture.* 2021; 188: 106319. https://doi.org/10.1016/j.compag.2021.106319

7. Michelucci U., Venturini F. Multi-Task Learning for Multi-Dimensional Regression: Application to Luminescence Sensing. *Applied Sciences*. 2019; 9(22): 4748. https://doi.org/10.3390/app9224748

8. Qin Y. *et al.* Acid Detection through a Rapid and Sensitive Amplified Luminescent Proximity Homogeneous Assay. *Toxins*. 2023; 15(8): 501. https://doi.org/10.3390/toxins15080501

9. Belyakov M.V. Optical spectral qualities of plant seeds with different moisture. *Bulletin NGIEI*. 2016; (4): 38–50 (in Russian). https://www.elibrary.ru/vyuqrb

10. Zhang D., Wang Z., Jin N., Gu C., Chen Y., Huang Y. Evaluation of Efficacy of Fungicides for Control of Wheat Fusarium Head Blight Based on Digital Imaging. *IEEE Access*. 2020; 8: 109876–109890. https://doi.org/10.1109/ACCESS.2020.3001652

11. Sanjay M., Kalpana B. Early Mass Diagnosis of Fusarium Wilt in Banana Cultivations using an E-Nose Integrated Autonomous Rover System. *International Journal of Applied Sciences and Biotechnology*. 2017; 5(2): 261–266. https://doi.org/10.3126/ijasbt.v5i2.17621

12. Karadağ K., Tenekeci M.E., Taşaltın R., Bilgili A. Detection of pepper fusarium disease using machine learning algorithms based on spectral reflectance. *Sustainable Computing: Informatics and Systems*. 2020; 28: 100299. https://doi.org/10.1016/j.suscom.2019.01.001

13. Hong S. *et al.* Visualization analysis of crop spectral index based on RGB-NIR image matching. *Spectroscopy and Spectral Analysis*. 2019; 39(11): 3493–3500 (in Chinese).

14. Yuan H. *et al.* Recent Advances in Fluorescent Nanoprobes for Food Safety Detection. *Molecules.* 2023; 28(14): 5604. https://doi.org/10.3390/molecules28145604

15. Liu S. *et al.* Fluorescence spectra of nutrients in chicken and skin under baking conditions. *Optik*. 2020; 18: 164795. https://doi.org/10.1016/j.ijleo.2020.164795

16. Alshehawy A.M., Mansour D.-E.A., Ghali M., Lehtonen M., Darwish M.M.F. Photoluminescence Spectroscopy Measurements for Effective Condition Assessment of Transformer Insulating Oil. *Processes*. 2021; 9(5): 732. https://doi.org/10.3390/pr9050732

17. Iyer S.N., Behary N., Nierstrasz V., Guan J., Chen G. Study of photoluminescence property on cellulosic fabric using multifunctional biomaterials riboflavin and its derivative Flavin mononucleotide. *Scientific Reports*. 2019; 9: 8696. https://doi.org/10.1038/s41598-019-45021-5

18. Ding K., Xiao L., Weng G. Active contours driven by region-scalable fitting and optimized Laplacian of Gaussian energy for image segmentation. *Signal Processing*. 2017; 134: 224–233. https://doi.org/10.1016/j.sigpro.2016.12.021

БИБЛИОГРАФИЧЕСКИЙ СПИСОК

1. Кирсанов В.В., Беляков М.В., Никитин Е.А., Благов Д.А., Михайличенко С.М. Спектральный анализ как инструмент определения качества смешивания многокомпонентной кормовой смеси. *Вестник Башкирского государственного аграрного университета.* 2023; (3): 41–46. https://www.elibrary.ru/rcobbx

2. Pavkin D.Y., Belyakov M.V., Nikitin E.A., Efremenkov I.Y., Golyshkov I.A. Determination of the Dependences of the Nutritional Value of Corn Silage and Photoluminescent Properties. *Applied Sciences.* 2023; 18(13): 10444. https://doi.org/10.3390/app131810444

3. Морозов Н.М., Кирсанов В.В., Ценч Ю.С. Историко-аналитическая оценка развития процессов автоматизации и роботизации в молочном животноводстве. *Сельскохозяйственные машины и технологии.* 2023; 17(1): 11–18. https://doi.org/10.22314/2073-7599-2023-17-1-11-18

4. Дорохов А.С., Кирсанов В.В., Павкин Д.Ю., Никитин Е.А., Михайличенко С.М., Благов Д.А. Анализ роботизированных кормораздатчиков для животноводческих комплексов по содержанию крупного рогатого скота. *Электротехнологии и электрооборудование в АПК*. 2023; 70(1): 94–104. https://doi.org/10.22314/2658-4859-2023-70-1-94-104

5. Buelvas R.M., Adamchuk V.I., Leksono E., Tikasz P., Lefsrud M., Holoszkiewicz J. Biomass estimation from canopy measurements for leafy vegetables based on ultrasonic and laser sensors. *Computers and Electronics in Agriculture*. 2019; 164: 104896. https://doi.org/10.1016/j.compag.2019.104896

6. Giménez-Gallego J., González-Teruel J.D., Soto-Valles F., Jiménez-Buendía M., Navarro-Hellín H., Torres-Sánchez R. Intelligent thermal image-based sensor for affordable measurement of crop canopy temperature. *Computers and Electronics in Agriculture.* 2021; 188: 106319. https://doi.org/10.1016/j.compag.2021.106319

7. Michelucci U., Venturini F. Multi-Task Learning for Multi-Dimensional Regression: Application to Luminescence Sensing. *Applied Sciences*. 2019; 9(22): 4748. https://doi.org/10.3390/app9224748

8. Qin Y. *et al.* Acid Detection through a Rapid and Sensitive Amplified Luminescent Proximity Homogeneous Assay. *Toxins*. 2023; 15(8): 501. https://doi.org/10.3390/toxins15080501

9. Беляков М.В. Оптические спектральные свойства семян растений различной влажности. *Вестник НГИЭИ*. 2016; (4): 38–50. https://www.elibrary.ru/vyuqrb

10. Zhang D., Wang Z., Jin N., Gu C., Chen Y., Huang Y. Evaluation of Efficacy of Fungicides for Control of Wheat Fusarium Head Blight Based on Digital Imaging. *IEEE Access*. 2020; 8: 109876–109890. https://doi.org/10.1109/ACCESS.2020.3001652

11. Sanjay M., Kalpana B. Early Mass Diagnosis of Fusarium Wilt in Banana Cultivations using an E-Nose Integrated Autonomous Rover System. *International Journal of Applied Sciences and Biotechnology*. 2017; 5(2): 261–266. https://doi.org/10.3126/ijasbt.v5i2.17621

12. Karadağ K., Tenekeci M.E., Taşaltın R., Bilgili A. Detection of pepper fusarium disease using machine learning algorithms based on spectral reflectance. *Sustainable Computing: Informatics and Systems*. 2020; 28: 100299. https://doi.org/10.1016/j.suscom.2019.01.001

13. Hong S. *et al.* Visualization analysis of crop spectral index based on RGB-NIR image matching. *Spectroscopy and Spectral Analysis*. 2019; 39(11): 3493–3500 (на кит. яз.).

14. Yuan H. *et al.* Recent Advances in Fluorescent Nanoprobes for Food Safety Detection. *Molecules.* 2023; 28(14): 5604. https://doi.org/10.3390/molecules28145604

15. Liu S. *et al.* Fluorescence spectra of nutrients in chicken and skin under baking conditions. *Optik*. 2020; 18: 164795. https://doi.org/10.1016/j.ijleo.2020.164795

16. Alshehawy A.M., Mansour D.-E.A., Ghali M., Lehtonen M., Darwish M.M.F. Photoluminescence Spectroscopy Measurements for Effective Condition Assessment of Transformer Insulating Oil. *Processes*. 2021; 9(5): 732. https://doi.org/10.3390/pr9050732

17. Iyer S.N., Behary N., Nierstrasz V., Guan J., Chen G. Study of photoluminescence property on cellulosic fabric using multifunctional biomaterials riboflavin and its derivative Flavin mononucleotide. *Scientific Reports*. 2019; 9: 8696. https://doi.org/10.1038/s41598-019-45021-5

18. Ding K., Xiao L., Weng G. Active contours driven by region-scalable fitting and optimized Laplacian of Gaussian energy for image segmentation. *Signal Processing*. 2017; 134: 224–233. https://doi.org/10.1016/j.sigpro.2016.12.021

19. Jin R., Weng G. Active contours driven by adaptive functions and fuzzy c-means energy for fast image segmentation. *Signal Processing*. 2019; 163: 1–10. https://doi.org/10.1016/j.sigpro.2019.05.002

20. Chaikov L.L. *et al.* Two Convenient Methods for Detection of Non-Dairy Fats in Butter by Dynamic Light Scattering and Luminescence Spectroscopy. *Applied Sciences*. 2023; 13(15): 8563. https://doi.org/10.3390/app13158563

21. Halachmi I., Ben Meir Y., Miron J., Maltz E. Feeding behavior improves prediction of dairy cow voluntary feed intake but cannot serve as the sole indicator. *Animal*. 2016; 10(9): 1501–1506. https://doi.org/10.1017/S1751731115001809

19. Jin R., Weng G. Active contours driven by adaptive functions and fuzzy c-means energy for fast image segmentation. *Signal Processing*. 2019; 163: 1–10. https://doi.org/10.1016/j.sigpro.2019.05.002

20. Chaikov L.L. *et al.* Two Convenient Methods for Detection of Non-Dairy Fats in Butter by Dynamic Light Scattering and Luminescence Spectroscopy. *Applied Sciences*. 2023; 13(15): 8563. https://doi.org/10.3390/app13158563

21. Halachmi I., Ben Meir Y., Miron J., Maltz E. Feeding behavior improves prediction of dairy cow voluntary feed intake but cannot serve as the sole indicator. *Animal*. 2016; 10(9): 1501–1506. https://doi.org/10.1017/S1751731115001809

ОБ АВТОРАХ

Дмитрий Андреевич Благов
кандидат биологических наук,
лаборатория инновационных технологий и технических средств кормления в животноводстве
aspirantyra2013@gmail.com
https://orcid.org/0000-0001-7826-5197

Евгений Александрович Никитин
кандидат технических наук, лаборатория инновационных технологий и технических средств кормления в животноводстве
evgeniy.nicks@yandex.ru
https://orcid.org/: 0000-0003-0918-2990

Михаил Владимирович Беляков
доктор технических наук, лаборатория инновационных технологий и технических средств кормления в животноводстве
bmw20100@mail.ru
https://orcid.org/0000-0002-4371-8042

Федеральный научный агроинженерный центр ВИМ,
Институтский проезд, 5, стр. 1, Москва, 109428, Россия

ABOUT THE AUTHORS

Dmitry Andreevich Blagov
Candidate of Biological Sciences,
Laboratory of Innovative Technologies and Technical Means of Feeding in Animal Husbandry
aspirantyra2013@gmail.com
https://orcid.org/0000-0001-7826-5197

Evgeny Alexandrovich Nikitin
Candidate of Technical Sciences, Laboratory of Innovative Technologies and Technical Means of Feeding in Animal Husbandry
evgeniy.nicks@yandex.ru
https://orcid.org/0000-0003-0918-2990

Mikhail Vladimirovich Belyakov
Doctor of Technical Sciences, Laboratory of Innovative Technologies and Technical Means of Feeding in Animal Husbandry
bmw20100@mail.ru
https://orcid.org/0000-0002-4371-8042

Federal Scientific Agroengineering Center VIM,
5/1 Institutsky proezd, Moscow, 109428, Russia