UDC 378
DOI: 10.15587/1729-4061.2023.290294

DEVELOPMENT OF A THERMODYNAMIC MODEL FOR OPTIMIZATION OF PROCESSES IN CROP PRODUCTION

Orken Mamyrbayev
Doctor PhD, Associate Professor*
Waldemar Wojcik
Doctor of Technical Science, Professor
Department of Electronic and Information Technologies
Lublin University of Technology
Nadbystrzycka str., 42A, Lublin, Poland, 20-501
Nataliia Titova
Doctor of Technical Sciences, Professor, Head of Department
Department of Biomedical Engineering
Odesa Polytechnic National University
Shevchenka ave., 1, Odesa, Ukraine, 65044
Sergii Pavlov
Doctor of Technical Sciences, Professor
Department of Biomedical Engineering and Optic-Electronic Systems
Vinnytsia National Technical University
Khmelnytske shose str., 95, Vinnytsia, Ukraine, 21021
Dina Oralbekova
Doctor PhD*
Assel Aitkazina
Corresponding author
Postgraduate Student
Department of Artificial intelligence and Big Data
Al-Farabi Kazakh National University
al-Farabi ave., 71, Almaty, Republic of Kazakhstan, 050040
E-mail: aitkazina.aseel@gmail.com
Nurdaulet Zhumazhan
Junior Researcher*
*Department of Artificial Intelligence
U. Joldasbekov Institute of Mechanics and Engineering
Kurmangazy str., 29, Almaty, Republic of Kazakhstan, 050010

The agricultural sector faces serious challenges related to climate change. These changes have the potential to reduce yields and food security, highlighting the importance of understanding and managing temperature dynamics. This work is the result of development a thermodynamic model that investigates the dynamics of temperature balance through heat energy transfer. A scheme of rheological heat exchange of an object with an insulated surface and graphs of irreversible rheological transformations are proposed. The main equation of heat exchange with a chemical reaction is given and the equation of the speed of heat energy transfer along the length of the object is derived. Further development of physical-mathematical models of the transformation of thermal energy into a set of states of the object is proposed. The experimental results fully correlate with the heat transfer equation. Samples with tomato seeds were irradiated with a photon irradiator with wavelengths of blue 450 nm, green 550 nm, red 650 nm with an exposure of 12/24 h. As a result, 90 % under the influence of the red spectrum of the photon irradiator for 24 h, which is 24 % more than the control sample. This will make it possible to assess the general temperature regime of agricultural objects and optimize the heating process. This study reveals the essence of temperature regulation at agricultural facilities using a thermodynamic model, which not only takes into account heat exchange, but also includes the influence of chemical reactions. The proposed thermodynamic model and associated equations provide a foundation for future research and practical applications that will ultimately benefit the agricultural industry, global food production

Keywords: thermodynamic model, rheological transitions, agriculture, algorithm, class diagram, photon irradiation

Received date 02.10.2023
Accepted date 06.12.2023
Published date 29.12.2023

How to Cite: *Mamyrbayev, O., Wojcik, W., Titova, N., Pavlov, S., Oralbekova, D., Aitkazina, A., Zhumazhan, N. (2023). Development of a thermodynamic model for optimization of processes in crop production. Eastern-European Journal of Enterprise Technologies, 6 (8 (126)), 25–00. doi: https://doi.org/10.15587/1729-4061.2023.290294*

1. Introduction

Climate change can affect agriculture in different ways. Beyond a certain temperature range, warming tends to reduce crop yields as crop development accelerates and, as a result, the amount of grain produced decreases. In addition, higher temperatures impair the plants' ability to obtain and use moisture.

Thus, the direct impacts of climate change on the agricultural sector include increased temperatures, weather variability, shifting agroecosystem boundaries, the emergence of invasive species and pests, and more frequent extreme weather events [1].

In solving the food problem, the biggest role is played by the production of agricultural products throughout the year, which is possible when using technologies of protected soil. For example, in Ukraine [2], one inhabitant has about 0.25 m^2 of protected soil area, while in France – 5.6 m^2, in the Netherlands – 5.4 m^2.

The experience of countries with developed agriculture shows that it is not just an increase in sown areas, but a maximum increase in plant productivity that is promising.

One of the main problems in obtaining high yields is planting material, namely seeds with low sowing qualities.

In the future, it is possible to get a good harvest and, accordingly, high-quality seeds using photonic seed activation technologies.

Therefore, research into the influence of thermodynamic processes on the growth and improvement of the quality of agricultural crops is relevant. Also relevant are studies that will influence seeds, causing structural changes in them that stimulate or inhibit the vital processes of plants in subsequent periods of their development.

2. Literary analysis and statement of the problem

The paper [3] presents the results of a study on the analysis of irradiation of seeds and seedlings with gamma rays and carbon ions to induce mutations. It has been shown that radiation with high linear energy transfer causes closely spaced DNA damage, regardless of the water content of the material, which can lead to the generation of rearrangements. Today, this technology is quite energy-consuming and has not been studied sufficiently, since gamma rays cause a large number of mutations. Considering that the detection efficiency varies depending on the type of mutation and the type of algorithm, the combined use of different algorithms is considered effective in achieving efficient and unbiased mutation detection [4]. Research [5] on the effect of irradiating seeds with a low-power continuous laser on germination, seedling growth and biochemical properties is gaining popularity. Overall, the effect of laser energy levels on germination and seedling growth was found in the following order: 75 mJ>50 mJ>25 mJ, where, as in the case of fat, protein and nitrogen content, the trend was as follows; 25 mJ>50 mJ and 75 mJ. However, this method can be used to improve seedling growth and mineral content where germination is low due to unfavorable conditions.

Publication [6] examines the effect of low-energy electromagnetic radiation on seeds of greenhouse crops. But this does not take into account the thermodynamic processes occurring in the seeds. The thermodynamic process is discussed in article [7]. However, it talks about using a combined infrared-convective dryer, which in our case is completely unsuitable due to the difference in planting material. In publication [8], the problem of short-term high-temperature processing of raw materials under the influence of infrared rays (micronization) was discussed. As a result, this increases the microbiological purity of raw materials. However, this changes the biological value of the seeds, for example, slight denaturation of proteins occurs.

Article [9] provides information on the coefficients of conversion of photon quantities into energy ones. This gives the opportunity to draw conclusions on optimizing the choice of photon emission ranges.

In work [10] the Boston lettuce variety was irradiated with a photoperiod of 16 hours for 35 days. Irradiation with photons of the violet, red, blue ranges with the addition of a white spectrum, as well as under cold white light. The maximum result corresponded to a combination of all three spectra. The option with cool white light was 10 % lower, and the red-blue combination showed a result 17 % lower than the maximum.

Some publications describe the use of machine learning to increase crop yields. This paper [11] describes a method for doing this optimization for the desired result of flavor by combining cyber-agriculture, metabolomic phenotype (chemotype) measurements, and machine learning. These are expensive technologies today, but they have a future.

Given that agriculture is the food security of any country, the listed studies only partially solve the problem of increasing productivity. It should be noted that some methods are expensive, unacceptable for mass use, and in some cases not completely safe. There remains an urgent need to solve the problem of increasing productivity in the most ecological, cheap and acceptable ways.

All of the above suggests that it would be advisable to conduct a research experiment to improve the quality of planting material using photonic technologies.

3. The aim and objectives of the study

The aim of the study is to create a thermodynamic model to study the dynamics of the temperature balance during photon irradiation of biological objects, to increase the germination of agricultural crops.

To achieve this aim, the following objectives are accomplished:

– to justify the principle of constructing a thermodynamic model for studying the dynamics of temperature balance;

– to present the dynamics of the temperature balance of planting material due to the transfer of thermal energy;

– to develop a block diagram of a block responsible for thermodynamic information processing;

– to develop an algorithm for conducting an experiment and simulate a class diagram;

– to present graphically the results of the experiment on the tomato variety «Rinato».

4. Materials and methods of research

The object of our research is a temperature balance of planting material. The main hypothesis of the study involves possibility of treating seeds with photon radiation of a certain spectrum, which will increase the germination and productivity of agricultural crops.

During the research, the following research methods were used:

– methods of the theory of interaction of laser radiation with biological objects – to study the influence of optical radiation on biological objects;

– methods of digital signal processing;

– methods of differential calculus;

– methods of mathematical modeling.

When constructing the thermodynamic model, the following simplifications were made: since the change in temperature is the driving force, it leads, first of all, to a change in the rate of mass transfer and chemical processes in the object.

The processes of heat and matter transfer in grains are similar. Molecular diffusion corresponds to heat transfer by molecular heat conduction, and convection diffusion corresponds to heat transfer by convection. All theoretical and experimental results obtained in the study of heat exchange processes [12–17] can be directly applied to diffusion processes. The experimental study of heat exchange is complicated by the need to carry out measurements in grains with a variable temperature. At the same time, the results are affected by the temperature dependence of the physical and chemical constants. For a stationary medium, the basic law of heat transfer (molecular thermal conductivity or thermal conductivity) is the Fourier law.

During the study, the following limitations and assumptions were adopted:

– small-sized glass containers for irradiation with dimensions of 40×15×15 cm are considered;

– one container is not irradiated, control sample;

– photon irradiation irradiation with wavelength: blue 450 nm, green 550 nm, red 650 nm and with exposure 12 and 24 hours;

– UML diagrams were used for modeling.

When conducting experimental studies, the following were used:

– software: unified modeling language UML;

– hardware: an experimental setup containing a thermodynamic information processing unit, an optical diffuser and a laser emitter with adjustable power.

5. Results of research on the development, modeling and practical implementation of a thermodynamic model for optimizing processes in agriculture

5. 1. Justification of the principle of constructing a thermodynamic model for studying the dynamics of temperature balance

The point of constructing a thermodynamic model is to highlight those features of the phenomenon and characteristics of the object that play a significant role in the range of events under consideration.

When external conditions change, changes also occur in the system. During the heat exchange process, the state of the system changes. But as the state changes, the internal energy also changes.

It is known that during heat exchange the process of energy transfer occurs at the molecular level.

Accordingly, when thermodynamic modeling it is necessary to take into account such parameters as: the amount of heat that is transferred through the surface per unit time, thermal conductivity coefficient, temperature gradient, time of transfer of thermal energy, direction of thermal energy and others.

Thus, the process of heat transfer from the irradiation source to the irradiation object will be described by differential equations.

5. 2. The temperature balance of planting material due to the transfer of thermal energy

For a stationary medium, the basic law of heat transfer (molecular thermal conductivity or thermal conductivity) is Fourier's law, according to which the heat flow is proportional to the temperature gradient [18]:

$$q = -\lambda \operatorname{grad} T \equiv -\lambda \frac{dT}{dy}, \qquad (1)$$

where q – the heat flow, that is, the amount of heat transferred through a unit of surface per unit of time; grad$T$ – temperature gradient; λ – thermal conductivity coefficient.

If the cause of the movement is a temperature difference, which leads to the transfer of heat in the grain, then it is considered to be free or natural convection. If the movement is caused by external forces, then the process is called forced convection. The most general description of transport processes is achieved if molecular flows are not separated from convective flows at all and use the mediated velocities of individual components, which include both molecular and convective transport. At the same time, the law of thermal diffusion in the form of Maxwell-Stefan [18–21] was obtained, and for more complex cases, a system of equations with forces of mutual friction was obtained. In the approximation of independent thermal diffusion, it is convenient to preserve the form of Fourier's laws, supplementing them with convection components expressing the convection transport associated with the movement of matter as a whole. If the linear speed of the latter is denoted by, then the Fourier law takes the form [18]:

$$q = -\lambda \operatorname{grad} T + C_P \rho \vartheta T, \qquad (2)$$

where c_p – heat capacity at constant pressure; ρ – density.

For the heat transfer process, a coefficient of thermal conductivity a is introduced, which is related to the usual coefficient of thermal conductivity by the ratio $a=\lambda/c_P\rho$. The equation of thermal conductivity in a stationary medium has the form [12]:

$$C_P \rho \frac{\partial T}{\partial \theta} = \operatorname{div} \lambda \operatorname{grad} T + q', \qquad (3)$$

where q' – density of heat sources, that is, the amount of heat released as a result of chemical reactions in a unit of volume per unit of time; θ – heat transfer time.

If the thermal conductivity coefficient λ can be considered constant, then equation (3) takes the form:

$$\frac{\partial T}{\partial \theta} = a \Delta T + \frac{1}{C_P \rho} q'. \qquad (4)$$

In the presence of convection, equation (4) must be supplemented with a convection component $v$grad$T$ (where v is the flow rate). For biochemical processes, the source of heat is the heat release of a chemical reaction, the main property of which is the dependence of its speed on temperature according to the Arrhenius law. Therefore, the density of heat sources is written as:

$$q' = Qz \cdot \exp\left(-E / RT_P\right), \qquad (5)$$

where Q – the thermal effect of the reaction; z – a constant; E – the activation energy, which is considered sufficiently large; R – universal gas table; T_p – the temperature of the biochemical reaction.

As a result of the accepted assumptions, the basic equation of heat exchange with a chemical reaction is obtained in the following form:

$$C_P \rho \frac{\partial T}{\partial \theta} = \operatorname{div}\left(\lambda \operatorname{grad} T - C_P \rho \vartheta T\right) + $$
$$+ Qz \cdot \exp\left(-E / RT_P\right). \qquad (6)$$

In a steady state, the products of a chemical reaction spread at a constant rate v_0. For such a regime, the heat transfer is described by the equation:

$$\frac{\partial}{\partial x} \lambda \frac{\partial T}{\partial x} - C_P \rho v_0 \frac{\partial T}{\partial x} + Qz \cdot \exp\left(-E / RT_P\right) = 0, \qquad (7)$$

where x – the direction of thermal energy propagation.

If the dependence of thermal conductivity on temperature is neglected (with a permissible change in the temperature), then equation (7) is simplified and takes the form:

$$a\frac{\partial^2 T}{\partial x^2}-\upsilon_0\frac{\partial T}{\partial x}+\frac{Q}{C_P\rho}Z\cdot\exp\left(-E/RT_P\right)=0. \quad (8)$$

From the heat balance equation for the temperature field,

$$C_P\rho\frac{\partial T}{\partial\theta}=-\frac{\partial q_x}{\partial x}. \quad (9)$$

Let's substitute q_x the following expression instead:

$$q_x=-\lambda\frac{\partial T}{\partial x}-\tau_P\frac{\partial q_x}{\partial\theta}, \quad (10)$$

where $\tau_P=c_P\rho$ is the time constant of the heat transfer process.

Assuming that λ and τ_P are constant, after differentiating by time t:

$$\tau_P\frac{\partial^2 T}{\partial\theta^2}+\frac{\partial T}{\partial\theta}-a\frac{\partial^2 T}{\partial x^2}+$$
$$+\upsilon_0\frac{\partial T}{\partial x}-\frac{Q}{C_P\rho}z\cdot\exp\left(-E/RT_P\right)=0. \quad (11)$$

Dividing equation (11) by the coefficient of thermal conductivity a:

$$\tau_P\frac{\partial^2 T}{\partial\theta^2}+\frac{\partial T}{\partial\theta}-$$
$$-\left(a\frac{\partial^2 T}{\partial x^2}-\upsilon_0\frac{\partial T}{\partial x}+\frac{Qz}{C_P\rho}\exp\left(-E/RT_P\right)\right)=0. \quad (12)$$

If to consider the process of heat energy transfer of a grain, for the case when this grain is in an environment with a constant temperature field [9]. Fig. 1 shows that the grain is a conventional rod with a constant insulated external environment, and the non-insulated part is a liquid or air that is a source of heat with temperature T_0. Let's divide the length of our object into conventional sections n of thickness $\Delta x\to 0$. Let's assume that heat is transferred to each subsequent section Δx only after the previous one has taken on the temperature of the source.

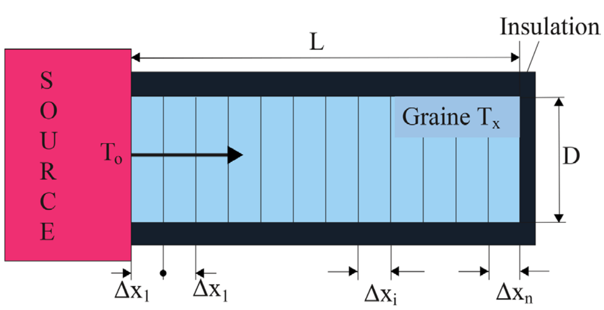

Fig. 1. Scheme of the rheological transition of heat of an object with an insulated surface

Each element of such a body undergoes a process of rheological transformation (heating), which according to [13] can be described by equation (12). In the first section $\Delta x\to dx$, there is a rheological transfer of thermal energy from the source to the first section (Fig. 2, curve 1). Due to this transfer, the object accumulates heat and heats up to a temperature of $T_{xi}=T_0$. The process of heating the site $\Delta x_1\to dx_1$ is shown in Fig. 2, curve 2. Dirac's integral pulse delta function is a rectangle of width Δx_1. Since, according to the condition of the problem, there is no flow of thermal energy through the surface, the task of transferring heat and heating the object will be symmetrical for each area. Thus, the process of heat transfer from the source to site 1 of the object will be described by a differential equation of type (12). The time of transfer of thermal energy from one area to another (flow time) $\Delta t_i=\theta_i-\theta_{i-1}$. When $\Delta t_i\to 0$ it is possible to write [9] that:

$$\tau_C\frac{dT_x}{dt}=kT_d\left(x,\theta\right), \quad (13)$$

where $\tau_C=PL/a$ – the thermal energy flow time constant; P – grain perimeter; k – thermal energy transfer coefficient.

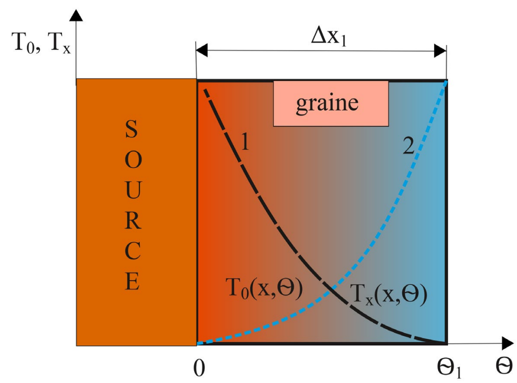

Fig. 2. Graphs of irreversible rheological transformations (curves 1 and 2) and integral impulse delta function of Dirac

Equation (13) describes the flow of thermal energy along the object. Therefore, assuming that $\partial\theta\approx dt$, equation (12) can be written as [12, 19, 20]:

$$\tau_P\frac{\partial^2 T}{\partial\theta^2}+\frac{\partial T}{\partial\theta}-$$
$$-\left(a\frac{\partial^2 T}{\partial x^2}-\upsilon_0\frac{\partial T}{\partial x}+\frac{Qz}{C_P\rho}\exp\left(-E/RT_P\right)\right)=\gamma(t), \quad (14)$$

where $\gamma(t)$ – the speed of heat energy transfer along the length of the object (heat energy flow).

Biochemical processes occurring in the biological environment are irreversible. therefore, let's present a physical model and graphs of irreversible rheological transformations (IRP) for rheological transitions in graphic form (Fig. 3–6).

The heat balance equation for such a heat energy transfer process in the x direction will have the form [13]:

$$\frac{\partial T(x,\theta)}{\partial\theta}=a\frac{\partial^2 T(x,\theta)}{\partial x^2}-\left[\gamma_1(x,\theta)+\gamma_2(r,t)\right], \quad (15)$$

where $\gamma_1(x,\theta)$ – the flow of thermal energy in the direction of the length of the conventional rod; $\gamma_2(r,t)$ – the flow of thermal energy during time t in the transverse direction with radius r.

Accumulation of heat in the conditional rod, based on the heat balance equation, is carried out according to the formula:

$$\gamma_1(x,\theta)=\tau'\frac{d^2T(x,\theta)}{d\theta^2}+\frac{dT(x,\theta)}{d\theta}-k'\frac{dT(r,t)}{dt}, \quad (16)$$

where τ' – the time constant of rheological transfer; k' – transmission coefficient; $T(r,t)$ – distribution of temperature by radius r by time t. The distribution of thermal energy along the radius of a conventional rod can be described by the equation:

$$\gamma_2(r,t)=\tau''\frac{d^2T(r,t)}{dt^2}+\frac{dT(r,t)}{dt}-k''\frac{dT(x,\theta)}{dt}, \qquad (17)$$

where τ'' – the time constant; k'' – gear ratio.

5. 3. The result of developing a block diagram for obtaining thermodynamic information

Let's take a closer look at the block diagram of the thermodynamic information processing unit (Fig. 4).

The thermodynamic information processing block operates as follows. In block 1, control is carried out using the LPT1 input/output port. Through X1, block 1 is connected to the computer via LPT1 port, configured for any of the I/O modes. The DD1 741S245(555AP6) chip performs the function of buffering the port data bus into the internal data bus of the device. The DD2 741S374 (555IP23) chip acts as a latch for the DD4 741S138 (555ID7) decoder chip, which ensures the selection of the required DD5 DD10 latch chip. The DD3 741S257 (555KP11) multiplexer chip transmits the device data bus to the LPT1 X1 port in two passes. Two passes are organized using the A/B control channel. The selection of channel A or B is carried out by transmitting the lower four bits of the data bus D0-D3 and a low-level signal is sent, and when transmitting the higher four bits of the data bus D4-D7, a high-level signal is sent to channel A/B. The PM1-PM2 microassembly prevents the high-level voltage from falling below the operating range. The DD5 chip performs the function of capturing information from the internal data bus, while simultaneously transferring control to the DA1 572PA1A digital-to-analog converter. The DA1 chip affects the level of the signal coming from one of the channels of the switching group of the DA5, DA7-DA9 590KN5 chips.

In block 2, the signal, passing through the source follower VT1, enters the amplifier stage (gain factor 10) on the transistor. The cascade mode is selected in such a way that the input bipolar signal is shifted to the region of negative voltages required for the operation of the ADC DA1. Due to the fact that the input capacitance of the latter is 300 pF, a powerful emitter follower on transistor VT3 is connected between the amplifier and the ADC. Using the DAC DA2 572 PA1A of block 1, the offset of the operating point of transistor VT1 is adjusted and thereby the constant shift at the emitter of transistor VT3 is adjusted. Resistor RP1 can be used to adjust the operating point. When the unit is overloaded, transistor VT2 goes into limiting mode and the signal at the ADC input does not leave the range –4...+1 V. Using the DA2 572 PA1A DAC of block 1, the reference voltage for the ADC is regulated, which is formed by a divider on resistor RP2, R10, an emitter follower on transistor VT4 and varies from –1 to –3 V. The digitized information from the ADC is sent via the data bus to the buffer DD1 555 AP6 chip. The microcircuit is clocked when writing to the decryption register of block 1 by the DD2 signal from port 14P and is transmitted to block 2. This device provides the ability to connect up to 12 measuring transducers that measure parameters of the physiological state of plant biosystems, including biopotentials; after which the information received according to the schemes described above is processed using a developed program on a PC.

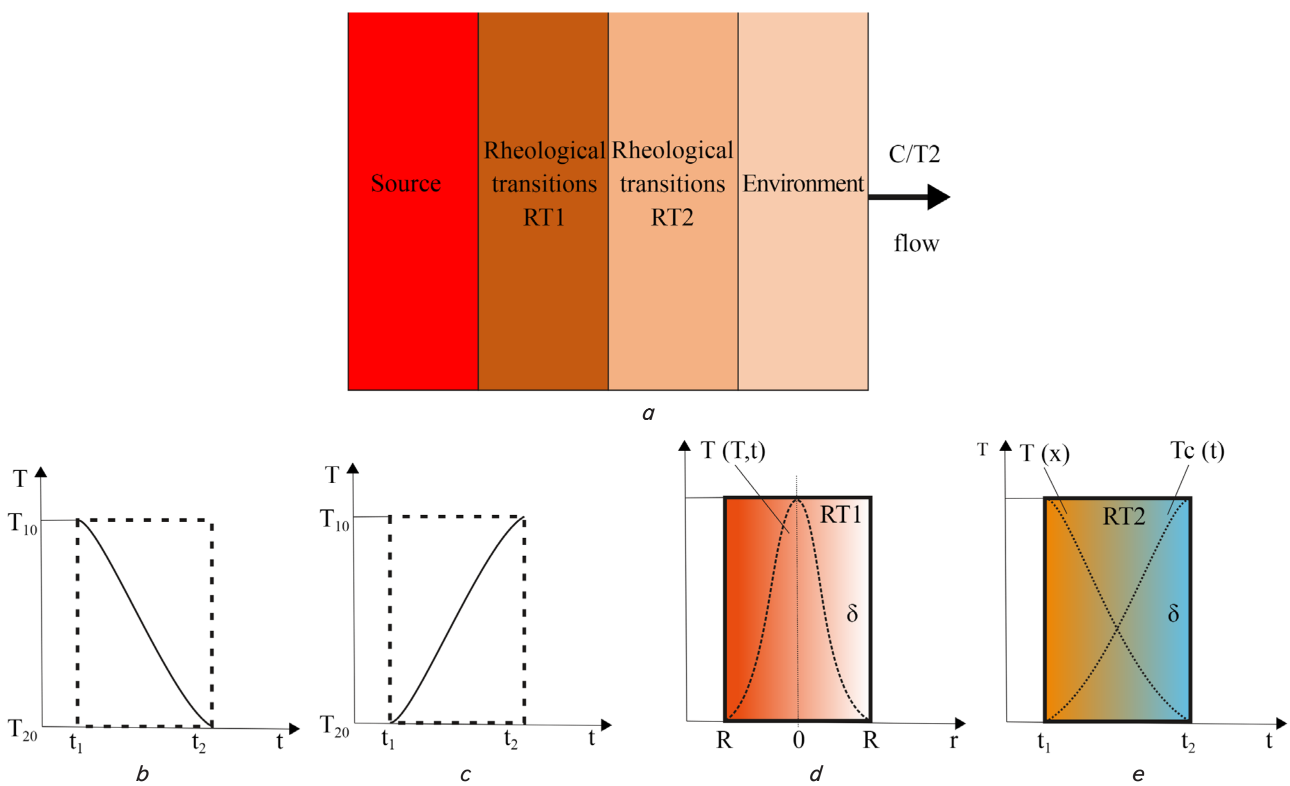

Fig. 3. IRP plots for rheological transitions: *a* – physical model; *b* – graph of the IRP of temperature transfer from the source to the biological object; *c* – IRP graph of temperature transfer to the core of the environment; *d* – graph of the Δ-function of the integral Dirac momentum for the first rheological transition RT1; *e* – graph of the integral Δ-function of the Dirac momentum for the second rheological transition RT2

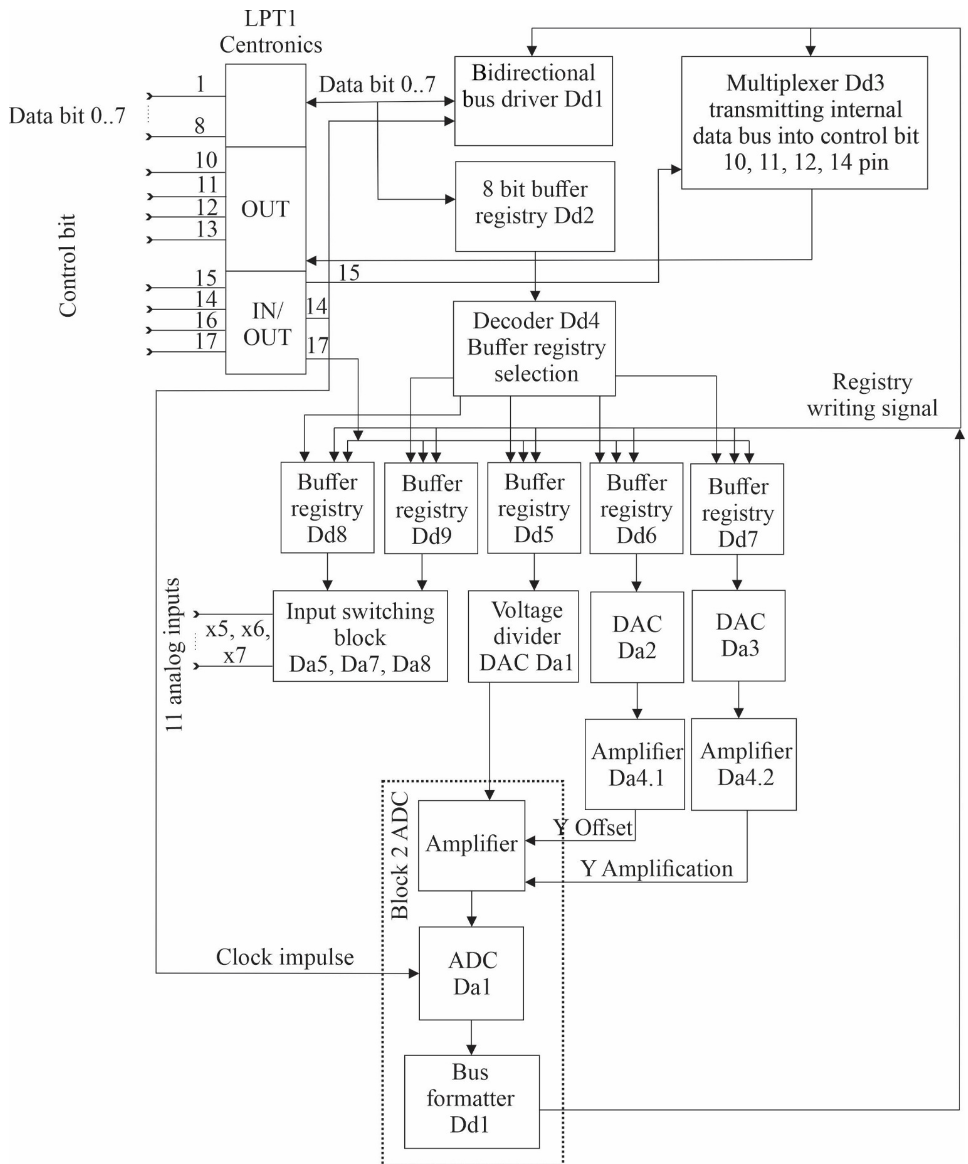

Fig. 4. Block diagram of the thermodynamic information processing unit

5. 4. The result of developing the experimental algorithm and class diagram model

Simulation of the experiment.

There are 4 containers with soil and planting material. Of them, 3 will be irradiated, 1 will be a control sample.

Input data are:

– temperature of the environment – T;

– time of irradiation – t;

– irradiation spectrum – S_i;

– result of experiment – R_{ex}.

Ability to control the experiment – automatically and manually.

Irradiation time has two variants – 12 hours of exposure, 12 hours of break; 24 hours of exposure, 24 hours of break.

The temperature near the containers is measured every 12 and 24 hours. There are 3 possible variants of radiation spectra. The experiment is considered finished when stairs appear in any of the containers. The results are recorded and stored in the database.

The simulated experiment was presented in the form of an algorithm (Fig. 5). All input and output data were taken into account in the algorithm and two modes of operation were shown – manual and automatic.

Visualization of the experiment was performed using UML, a class diagram was used (Fig. 6).

The simulation of the experiment was performed using a class diagram (Fig. 6).

A class diagram is great for visualizing this experiment because of the following factors:

1. Data structure, that is, it is clearly defined which classes exist in the system (for example: Container, ExperimentResult), which attributes and methods they have.

2. Relationships – shows how classes interact with each other. For example, in our situation, the Experiment includes many containers and has aggregation relationships with them.

3. Clear visualization – our diagram provides a graphical representation that makes it easier for everyone involved in the project to understand the structure of the system and its components.

4. Development Aid – the diagram is a source of information for developers who can use it as a starting point for writing code if needed in the future.

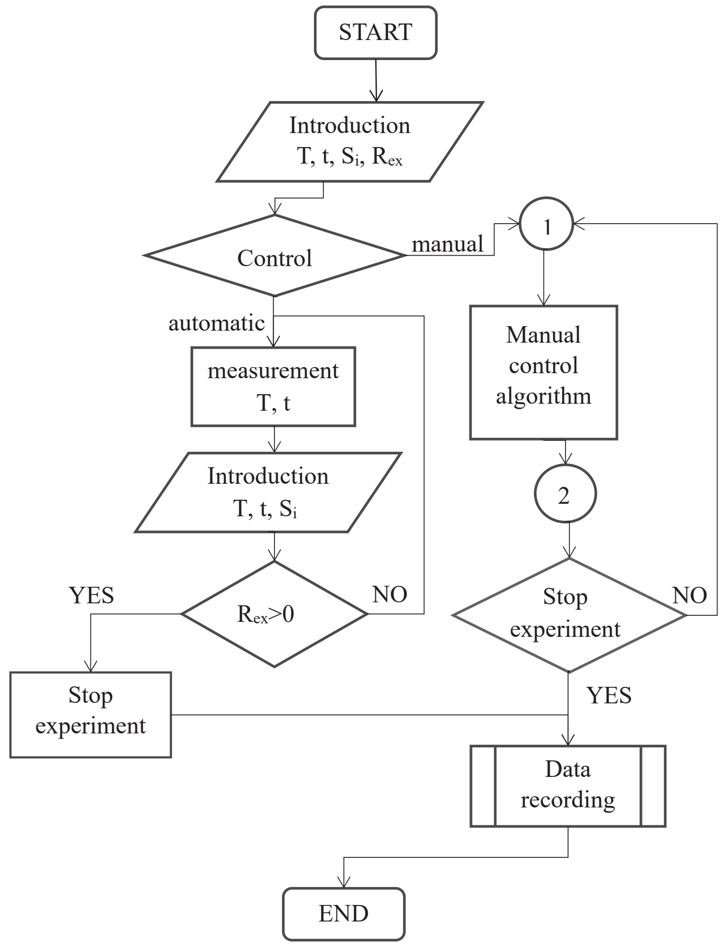

Fig. 5. The algorithm of the future experiment

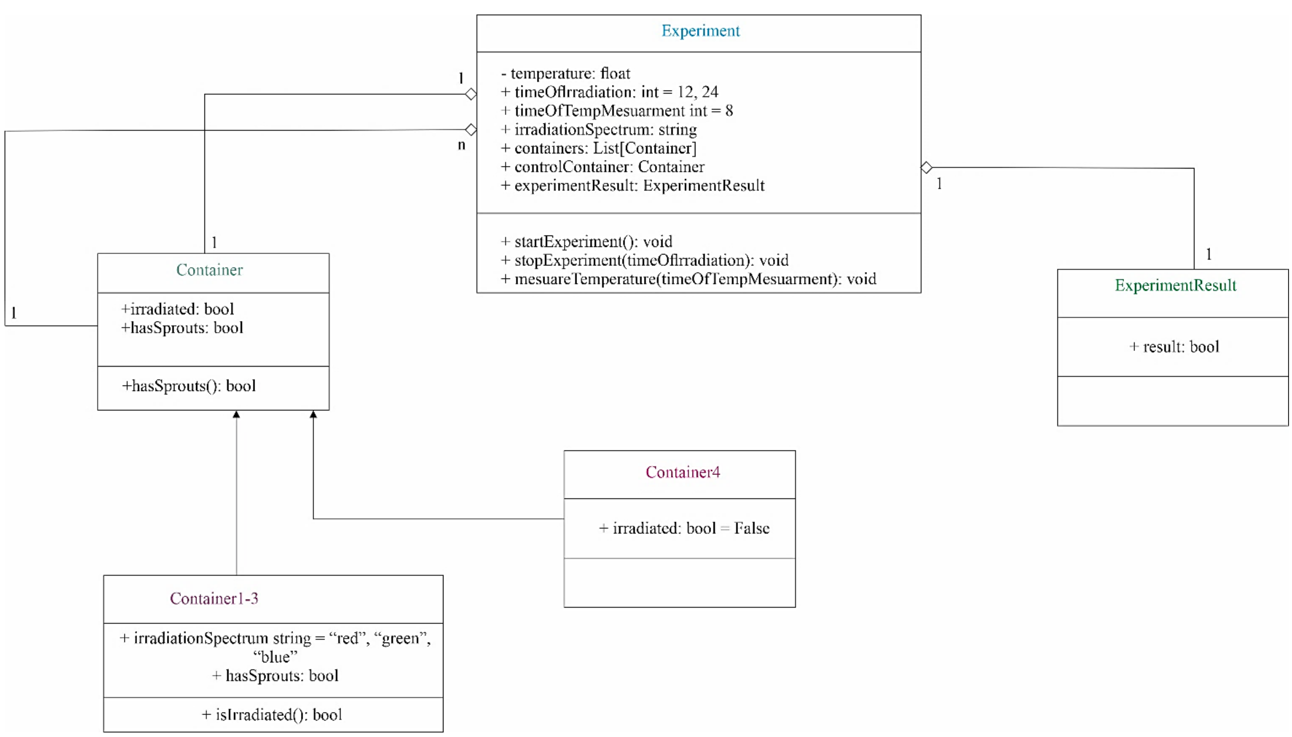

Fig. 6. Class diagram of the future experiment, where:
– privat – access only inside the class, + public – access inside and outside the class,
protected – access inside the package and its subclasses

Thus, with the help of a class diagram, a clearer visualization of our experiment is achieved. This gives the opportunity to analyze and improve, that is, to make changes as needed.

5. 5. Graphical results of the experiment

After conducting a production experiment on irradiating containers with planting material, namely the «Rinato» tomato variety, let's record the results.

Fig. 7 shows the results of a seed germination experiment with irradiation for 24 hours.

Fig. 8 shows the results of a seed germination experiment with irradiation for 12 hours.

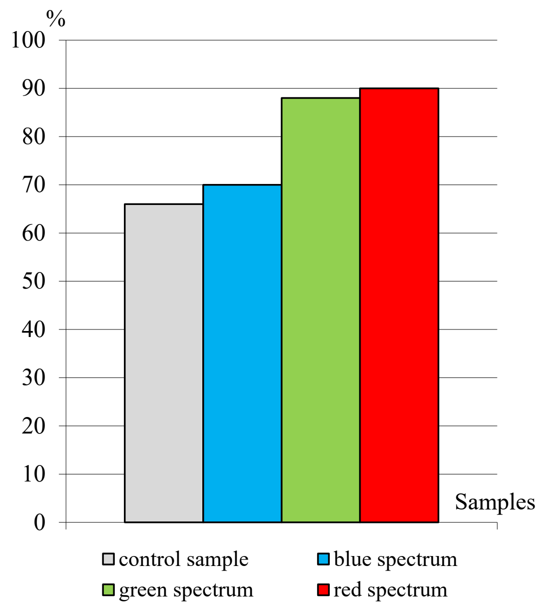

Fig. 7. Dependence of tomato seed germination on the irradiation spectrum (24 h)

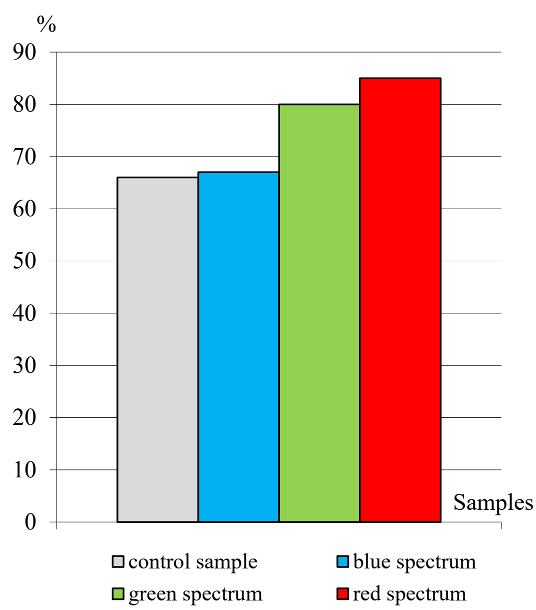

Fig. 8. Dependence of tomato seed germination on the irradiation spectrum (12 h)

As a result, the germination of tomato seeds in the control sample, which was not irradiated, was 66 % in both cases. All obtained data are presented in Table 1.

Table 1

Experimental results. Seed germination in %

Irradiation time	Photon irradiation spectrum			
	Control sample	Blue spectrum	Green spectrum	Red spectrum
12 h	66 %	67 %	80 %	85 %
24 h	66 %	70 %	88 %	90 %

From the table with the experimental results, it is possible to conclude that the maximum result for all three spectra of photon radiation is achieved around the clock. However, it should be noted that the red spectrum gives the best results for any irradiation period, namely 90 % at 24 hours of irradiation and 85 % at 12 hours of irradiation.

6. Discussion of research results on the development, modeling and practical implementation of a thermodynamic model for optimizing processes in agriculture

The result of modeling a thermodynamic model that explores the dynamics of the temperature balance due to the transfer of thermal energy is presented in the form of equations (11) and (12) for assessing the general temperature state of a biological object. This shows that the distribution of the temperature field in a biological object is nonlinear and makes it possible to optimize the heating processes both in time and in terms of the power of thermal radiation (equation (16)). In addition, this demonstrates that the process of warming up a biological organism can be done by draining thermal energy.

The presented mathematical models of temperature distribution in a certain object in time and coordinate describe only the process of transfer of thermal energy through the rheological transition zone (Fig. 2, 3). At the moment, in a biological object, thermodynamic processes are used to warm up or cool some elements of the object, which are located at some distance from the heat source. In fact, the drain of thermal energy that passed through the rheological transition zone during the study of real processes of energy and mass transfer in the object is used.

In [14] considered a thermodynamic model for cold-blooded biological organisms (aquatic) and accordingly took into account other indicators of the environment and the studied samples. In [8, 10] photon irradiation of biological objects was carried out, but the dynamics of temperature balance and rheological transitions were not considered.

Evaluating the results of our experiment, it is possible to conclude that the highest percentage of germination of tomato seeds is observed when irradiated with the red spectrum for 24 hours – 90 %. This is 24 % higher than the control sample. It can also be noted that the germination spectrum of blue irradiation is almost equal to the control sample. This partly correlates with some publications on this topic [6, 7, 9].

To ensure optimal treatment regimes for seeds of greenhouse crops, leading to increased yields, a wavelength range of 650 nm (red irradiation spectrum) was experimentally established (Fig. 7, 8).

There are some limitations to using this method that should be noted. For the most part, this technology can be used in closed ground, that is, in greenhouses. However, the progress of this study can be improved by further research. Many other aspects may require further study.

The content of photosynthetic pigments in plant leaves is an important indicator of their development and depends on the influence of various natural factors. The next stage will be the study of chlorophyll «a» pigments in tomato leaves after their seeds have been treated with photon radiation.

7. Conclusions

1. The principle of constructing a thermodynamic model for studying the dynamics of temperature balance was substantiated.

The following parameters were taken into account: the amount of heat that is transferred through the surface per unit time, thermal conductivity coefficient, temperature gradient, time of transfer of thermal energy, direction of thermal energy and others. These parameters indicate the accuracy and suitability of the model.

2. The dynamics of the temperature balance of planting material due to the transfer of thermal energy. A diagram of the rheological heat transfer of an object with an isolated surface and graphs of rheological transformations are shown. The basic equation of heat transfer during a chemical reaction is given and the equation for the rate of transfer of thermal energy along the length of an object is derived. Further development of physical and mathematical models for the transformation of thermal energy into a set of object states is also proposed. This will allow to assess the overall temperature regime of agricultural facilities and optimize the heating process.

This shows that the distribution of the temperature field in a biological object is nonlinear and makes it possible to optimize the heating processes both in time and in terms of the power of thermal radiation (equation (16)).

The results of mathematical modeling of the thermodynamic model will make it possible to develop an effective, energy-saving, environmentally friendly technology to increase the yield and quality of greenhouse crops. As well as technical means for pre-sowing treatment of greenhouse crop seeds with photon radiation.

3. A block diagram of the block that is responsible for thermodynamic information processing has been developed. This device provides the ability to connect up to 12 measuring transducers that measure parameters of the physiological state of plant biosystems, including biopotentials; after which the information received according to the schemes described above is processed using a developed program on a PC.

4. An algorithm for conducting an experiment is presented and a class diagram is modeled. Thus, with the help of a class diagram, a clearer visualization of our experiment is achieved. This gives the opportunity to analyze and improve, that is, to make changes as needed.

5. The results of the experiment are shown in the form of graphical information. It can be concluded that the maximum effect of germination of tomato seeds when irradiated with the red spectrum for 24 hours is 90 %. Which is 24 % more than the control sample.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

This research has been funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP 19677201).

Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Peace for Food: Our Istanbul Roundtable. Available at: https://www.businessatoecd.org/blog/peace-for-food-our-istanbul-roundtable
2. Statistical information. State Statistics Service of Ukraine. Available at: https://www.ukrstat.gov.ua/
3. Hase, Y., Satoh, K., Kitamura, S. (2023). Comparative analysis of seed and seedling irradiation with gamma rays and carbon ions for mutation induction in Arabidopsis. Frontiers in Plant Science, 14. doi: https://doi.org/10.3389/fpls.2023.1149083
4. Kosugi, S., Momozawa, Y., Liu, X., Terao, C., Kubo, M., Kamatani, Y. (2019). Comprehensive evaluation of structural variation detection algorithms for whole genome sequencing. Genome Biology, 20 (1). doi: https://doi.org/10.1186/s13059-019-1720-5
5. Urva, Shafique, H., Jamil, Y., Haq, Z. ul, Mujahid, T., Khan, A. U. et al. (2017). Low power continuous wave-laser seed irradiation effect on Moringa oleifera germination, seedling growth and biochemical attributes. Journal of Photochemistry and Photobiology B: Biology, 170, 314–323. doi: https://doi.org/10.1016/j.jphotobiol.2017.04.001
6. Nikiforova, L. E. (2008). Study of the effect of low-energy electromagnetic radiation on the seeds of greenhouse crops. Proceedings of the Tavri State Agro-Technological University. Melitopol.
7. Geng, Z., Wang, H., Torki, M., Beigi, M., Zhu, L., Huang, X. et al. (2023). Thermodynamically analysis and optimization of potato drying in a combined infrared/convective dryer. Case Studies in Thermal Engineering, 42, 102671. doi: https://doi.org/10.1016/j.csite.2022.102671
8. Minevich, I. E., Uschapovsky, I. V. (2021). Influence of IR radiation on the biological value of flax seeds. Agrarian Science, 11-12, 144–146. doi: https://doi.org/10.32634/0869-8155-2020-343-11-134-136

9. Boos, G. V., Prikupets, L. B., Terehov, V. G., Tarakanov, I. G. (2017). Studies in the field of plant irradiation with LEDs. The 10th Asia Lighting Conference. Shanghai.
10. Lin, K.-H., Huang, M.-Y., Huang, W.-D., Hsu, M.-H., Yang, Z.-W., Yang, C.-M. (2013). The effects of red, blue, and white light-emitting diodes on the growth, development, and edible quality of hydroponically grown lettuce (Lactuca sativa L. var. capitata). Scientia Horticulturae, 150, 86–91. doi: https://doi.org/10.1016/j.scienta.2012.10.002
11. Johnson, A. J., Meyerson, E., de la Parra, J., Savas, T. L., Miikkulainen, R., Harper, C. B. (2019). Flavor-cyber-agriculture: Optimization of plant metabolites in an open-source control environment through surrogate modeling. PLOS ONE, 14 (4), e0213918. doi: https://doi.org/10.1371/journal.pone.0213918
12. Stenzel, Y. I., Zlepko, S. M., Pavlov, S. V. (2013). Physical and mathematical modeling of thermodynamic methods of diagnosing the state of human health. Optical-electronic information and energy technologies. Vinnytsia, 66–72.
13. Wojcik, W., Pavlov, S. (Eds.) (2022). Highly linear Microelectronic Sensors Signal Converters Based on Push-Pull Amplifier Circuits. Lublin, 283.
14. Titova, N. V., Stenzel, Y. I., Pavlov, S. V., Zlepko, S. M. (2017). Modeling of thermodynamic methods in biological objects for reproduction in the fishery. Application of lasers in medicine and biology: materials of the XLVI international scientific and practical conference. Kharkiv: FOP Petrov V., 137–139.
15. Horobets, V. G. (2015). Heat engineering and use of heat in agriculture. Kyiv, 389.
16. Didur, V. A., Struchaev, M. I. (2008). Heat engineering, heat supply and use of heat in agriculture. Kyiv: Agrarian Education, 233.
17. Spivak, O. Yu., Resident, N. V. (2021). Heat and mass exchange. Part I: study guide. Vinnytsia: VNTU, 113.
18. Rubin, A. B. (1999). Biophysics. Vol. 1. Theoretical biophysics. Moscow: Moscow University Publishing House, 448.
19. Wójcik, W., Pavlov, S., Kalimoldayev, M. (Eds.) (2019). Information Technology in Medical Diagnostics II. CRC Press. doi: https://doi.org/10.1201/9780429057618
20. Wójcik, W., Smolarz, A. (Eds.) (2017). Information Technology in Medical Diagnostics. CRC Press. doi: https://doi.org/10.1201/9781315098050
21. Yessenova, M., Abdikerimova, G., Adilova, A., Yerzhanova, A., Kakabayev, N., Ayazbaev, T. et al. (2022). Identification of factors that negatively affect the growth of agricultural crops by methods of orthogonal transformations. Eastern-European Journal of Enterprise Technologies, 3 (2 (117)), 39–47. doi: https://doi.org/10.15587/1729-4061.2022.257431