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Stimulation of the Liver Regeneration with Bone Marrow Mesenchymal Stem Cells

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Abstract. The main objective of our experiment was to prove the effect of mesenchymal stem cells of bone marrow (MSCs) on the stimulation of liver regeneration. The attention has been paid to adaptation of stem cells to the new environment and their transfer to anatomical structures. The experiment included 40 male Sprague Dawley (SD) rats aged 10 to 12 weeks. Biomodels were divided into five groups in the same number (n=8). Group 1 consisted of a control sample of eight healthy rats. Group 2 consisted of eight rats after liver resection without application of MSCs. Group 3 was after liver resection and application of MSCs. Group 4 after liver injury induce with Thioacetamide (TAA), without transplantation of MSCs. Group 5 was after chemical damage to the liver by TAA administration and MSCs transplantation. The process of stimulation of the liver was observed based on the laboratory values of alanine aminotransferase (ALT), albumin and bilirubin. The weight of the rats in each group was also compared. Animals were sacrificed after 1 day, 7 days, 14 days, and 21 days. In our experiment we found a statistically significant decrease in ALT ($P \leq 0.001$) and bilirubin ($P \leq 0.001$) was observed in the groups 3 and 5 (treated with MSCs) compared to the groups without MSCs (Groups 2 and 4). The increase in the albumin levels in the groups 3 and 5 was statistically significant. The results of our experiment led us to the conclusion, the transplantation of MSCs has important effect for the treatment and stimulation of liver regeneration following injury. MSCs administration may be extremely useful in a number of clinical applications in the treatment of liver tumors. It will allow us to perform extensive resection of the liver without risk of liver failure

Keywords: stem cells, thioacetamid, liver resection, liver regeneration



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INTRODUCTION

Recent research findings highlight the potential for the use of stem cells in the future [1]. Mesenchymal stem cells are multipotent cells able of self renewal and differentiation into several cell lines, including chondrocytes, osteoblasts and adipocytes. This type of stem cells is usually isolated from bone marrow, they can also be obtained from several neonatal and adult tissues, including umbilical cord, and fat tissue [2]. Under rare conditions, adult SCs can be reprogrammed and produce cell lines different from the original tissue. This phenomenon is called plasticity of stem cells. A change in the differentiation potential occurs when the stem cell leaves its original site and settles in the new tissue and then under the influence of new signal molecules, it can change the destiny of the stem cell so much that it starts producing different cell lines [3; 4]. All these properties of MSCs, together with the enormous ability to differentiate into specialized cells – in our case hepatocytes – make them the most suitable candidates for cell therapy in the area of liver regeneration [5; 6].

Primary liver cancer is the second leading cause of cancer related death worldwide and therefore a major public health challenge. Primary liver cancer includes hepatocellular carcinoma, intrahepatic cholangiocarcinoma, and other rare tumors, notably fibrolamellar carcinoma and hepatoblastoma [7]. The tumor size is one of the important predictive factors affecting treatment and early diagnosis is decisive for favorable prognosis [8].

In the liver tumors, the liver resection is the most effective treatment. Statistics show that curative resection is possible in about 47% of the patients with primary liver cancer, about 20% of the patients are inoperable before surgery, and 33% of the patients at surgery. The result of liver resections depends to a large extent on the functional capacity of the remaining liver residue. It is known that 20% of healthy liver is sufficient to maintain liver function after resection. In a cirrhotic liver, a minimum of 40% well-perfused liver-volume must remain *in situ* after resection. Liver resections in cirrhotic patients show a significantly increased mortality and morbidity, the functional capacity of the remaining liver residue is substantially reduced. Postoperative liver failure is the most serious and life-threatening complication after liver resection [9].

Existing experimental studies on mice by M. Kaibori et al. [10], "attempted to stimulate liver regeneration by stem cell transplantation (SCs) taken from bone marrow of mice. After isolation of SCs, they were subsequently transplanted by injection into two experimental groups. In the first experimental group the MSCs were transplanted by injection into the portal vein. In the second experimental group the MSCs were transplanted by injection into the tail vein, and in the third control group physiological solution was injected into the portal vein" [10] performed 70% of hepatectomy, which was

described by Higgins and Anderson [11]. The mice were divided into three groups as listed and individual solutions were injected into the liver immediately after hepatectomy. In the experiment, they focused on assessing the liver regeneration according to the size, liver tissue histology, and statistical analysis of the results. Transplantation of MSCs has shown a great promise to improve the tissue regeneration in various acute and chronic diseases [10].

The main purpose of this study was to confirm and manifest the effect of bone marrow-derived mesenchymal stem cells on the stimulation of liver regeneration after injury.

MATERIALS AND METHODS

All the experimental conditions of the experiment were in compliance with the European rules of ethical standards of animal care. The experiment was approved by the Ethics committee of the Faculty of Medicine, University of Pavol Jozef Šafárik, and the State Veterinary and Food Administration of the Slovak Republic. Forty male Sprague Dawley (SD) rats at the age of ten to twelve weeks with an initial weight of 250 to 350 grams were included. The biomodels were randomly divided into five groups in the same number (n=8):

Group 1: Healthy rats were a control group.

Group 2: Rats after radical resection of the liver without application of MSCs.

Group 3: Rats after radical resection of the liver with application of MSCs.

Group 4: Rat after liver damage with TAA (thioacetamide) induction without application of stem cells.

Group 5: Rat after liver damage with TAA induction with application of stem cells into the liver.

Mechanical damage of the liver – liver resection. At liver resections in experimental rats we proceeded taken into account the individual lobes of the liver. The experimental animals used in the study began to starve 12 hours before surgery, in the morning we took away water. The animals were anaesthetized by intramuscular administration of Thiopental at a dose of 15 mg/kg, after which the experimental animals were placed in the incubator for 10-15 min. Once the required depth of anaesthesia had been reached, we started operating. After placing the experimental animal on the operating table, we prepared an operating field. We performed a laparotomy. After opening the abdominal cavity, we performed radical resection of the liver by ligating the individual lobes of the liver and then resecting them (Fig. 1, 2). Hepatic resections in the rats of the groups observed were performed at the range of 70% as described Higgins and Anderson [11]. Hepatic impairment by TAA (Thioacetamide). TAA is a chemical used to make catalysts, stabilizers, polymerization inhibitors, galvanic cells, pesticides, and dyes. It seriously damages the liver [12].



Figure 1. Ligation of the liver lobe – hemihepatectomy

Twenty-four hours before the intraperitoneal administration of TAA, we took blood from the tail vein approximately 2 ml for laboratory testing of ALT, bilirubin, and albumin. Subsequent samplings were performed 24 hours after TAA administration on days 1, 7, 14, and 21. The hepatic damage was induced by intraperitoneal TAA at the dose of 175 mg/kg [13]. The experimental animals were separated and labelled. The weight loss in a given group due to induced liver failure was continuously detected. Before the surgery, the animals were anesthetized using the intraperitoneal administration of thiopental. As an analgesic, tramadol hydrochloride (Grünenthal GmbH, Aachen, Germany) was administered intramuscularly at a dose of 5 mg/kg in the post-operative period.

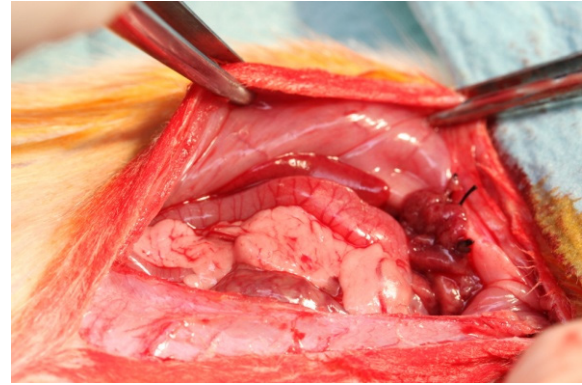


Figure 2. Condition after liver resection

All the animals in the study began to starve 12 hours before the stem cell application. As anaesthetic used thiopental 15 mg/kg. After preparation of the operating field, the longitudinal incision opened the abdominal cavity from the processus xiphoideus downwards. Suspension of mesenchymal stem cells was given via an insulin syringe to the vena portae. The MSC suspension (1×10^6 in a volume of 1 ml of culture solution). In the experimental rats after previous liver resection, the stem cells were applied to the vena portae. In the experimental rats with chemical impairment of the liver by TAA, the stem cells were also transplanted into the vena portae (Fig. 3, 4). The abdominal cavity wall was closed in individual anatomical layers.



Figure 3. Application of MSCs to the v. portae

The experiment was continuously finished on day 21 after transplantation of the MSCs. The rats were anaesthetized with an increased dose of thiopental anaesthesia, and then the animals were sacrificed by decapitation. The liver collection itself was performed after the preparation of the field under aseptic conditions. In rats after the previous resection, only the remaining part was resected, which was 20-30%. In rats with chemical damage of the liver after TAA administration, hepatectomy was performed.

RESULTS AND DISCUSSION

The results were obtained by comparing the ALT, albumin and bilirubin values in the individual groups of experimental animals, typification of mesenchymal stem cells, histopathological and microscopic analysis.

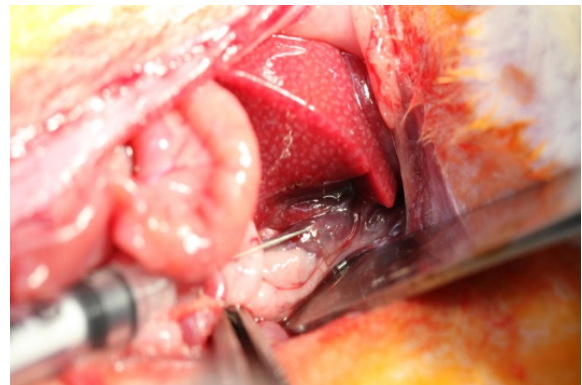


Figure 4. Presented v. portae

Group 2 – the experimental rats with mechanically damaged liver after resection without MSCs transplantation – in this group an increase in the laboratory ALT values, bilirubin and, on the contrary, a decrease in the albumin values was observed;

Group 3 – the experimental rats with damaged liver after resection and with MSCs transplantation – in this group, an increase in the laboratory values of ALT, bilirubin immediately after resection was observed. In the following days, ALT and bilirubin decreased and albumin increased. This result demonstrates the therapeutic effect of transplanted mesenchymal cells and their positive effect on the liver regeneration.

Group 4 – the experimental rat with the liver chemically impaired with TAA without MSCs transplantation – in this group, likewise in the group 2 an increase

of laboratory values of ALT, bilirubin, and, on the contrary, decreases in the albumin values were observed. In the following days, the values did not alter as regards ALT and bilirubin. The albumin value did not increase.

Group 5 – the experimental rats with damaged liver by TAA application with MSCs transplantation – in

this group, an increase in laboratory values of ALT, bilirubin was observed after resection. In the following days, a decrease in the ALT and bilirubin values, and an increase in albumin were observed. The graphical representation of our results is at Tables 1-4 and in Figures 5-12.

Table 1. The alanine transaminase (ALT) values obtained in the individual monitored groups

	0 day	1 st day	7 th day	14 th day	21 st day
Group 1	0.76	0.65	0.57	0.54	0.71
Group 2	0.66	12.92	13.16	13.19	10.41
Group 3	0.59	12.5	7.92	3.43	2.21
Group 4	0.73	16.89	16.25	20.08	16.98
Group 5	0.69	20.85	14.44	4.69	1.48

Table 2. The albumin values obtained in the individual monitored groups

	0 day	1 st day	7 th day	14 th day	21 st day
Group 1	26.78	34.91	34.21	33.47	30.79
Group 2	29.53	34.25	30.90	24.37	19.82
Group 3	28.48	34.22	29.43	26.76	22.73
Group 4	29.73	29.27	28.15	29.07	23.16
Group 5	39.25	27.23	32.65	29.12	29.99

Table 3. The bilirubin values obtained in the individual monitored groups

	0 day	1 st day	7 th day	14 th day	21 st day
Group 1	4.06	4.38	2.25	3.08	4.21
Group 2	3.47	12.01	10.21	10.25	11.77
Group 3	4.43	12.22	5.33	5.73	4.01
Group 4	4.61	12.85	10.85	10.85	10.82
Group 5	5.07	14.12	6.96	4.95	3.2

Table 4. The weight values obtained in the individual monitored groups

	0 day	1 st day	7 th day	14 th day	21 st day
Group 1	435.25	454.87	467.375	471.87	479.75
Group 2	447.75	429.5	418	410	401.37
Group 3	435.125	431.12	435	442	448.62
Group 4	430.62	452.62	463.12	457.5	454.12
Group 5	436.25	423.37	432.5	442.37	452.64

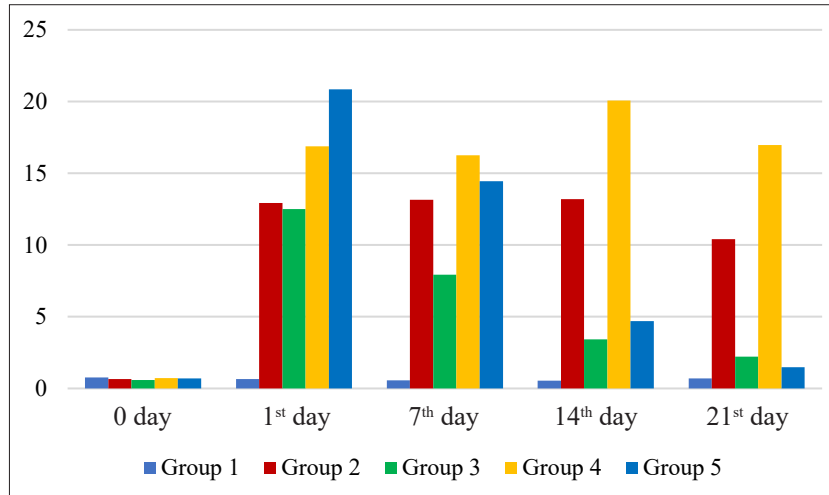


Figure 5. Graphical evaluation of ALT

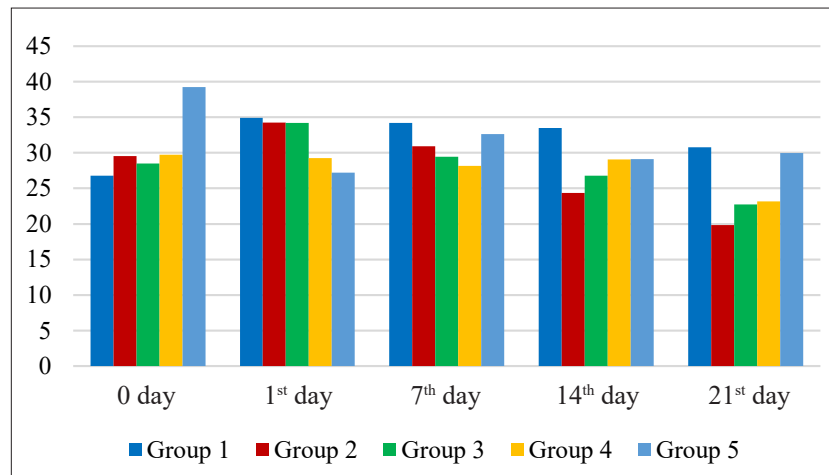


Figure 6. Graphical evaluation of the mean values of albumine

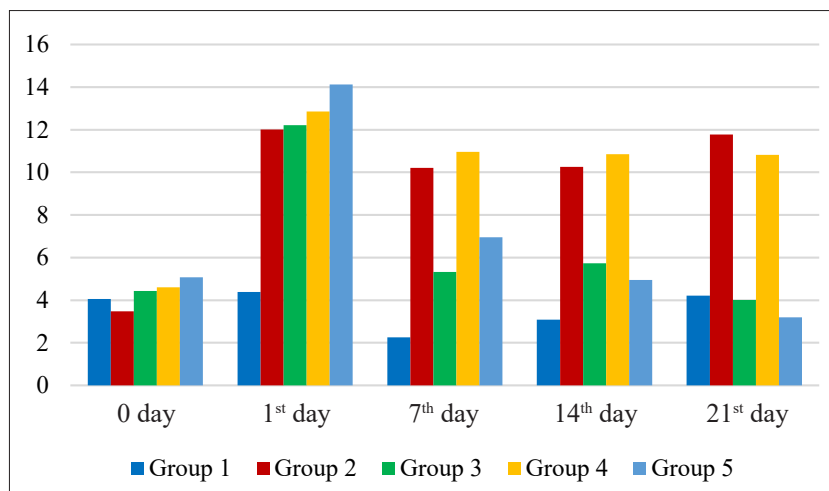


Figure 7. Graphical evaluation of bilirubin

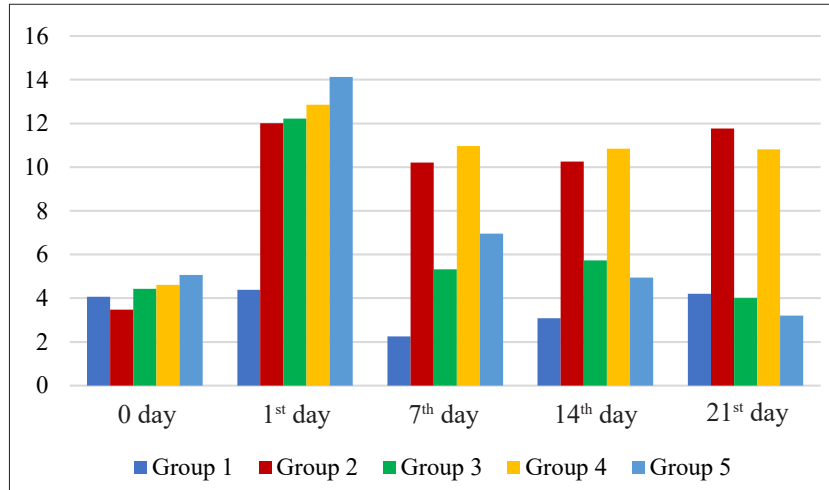


Figure 8. Weight dependence chart

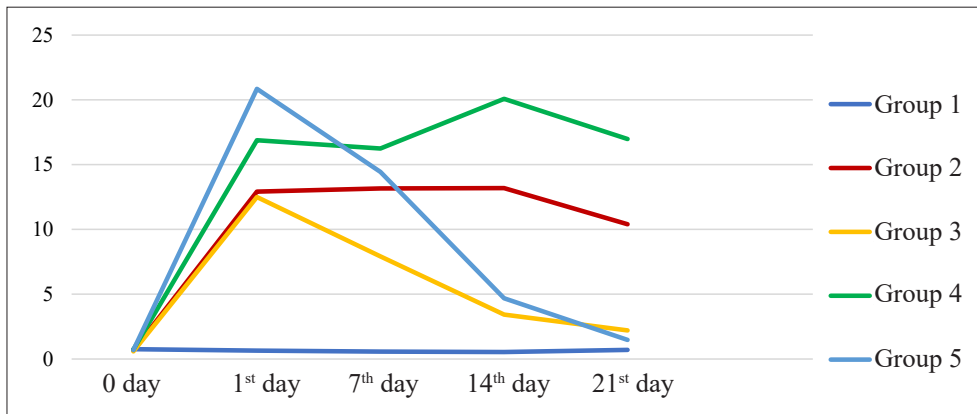


Figure 9. The graphic evaluation of the alanine transaminase (ALT)

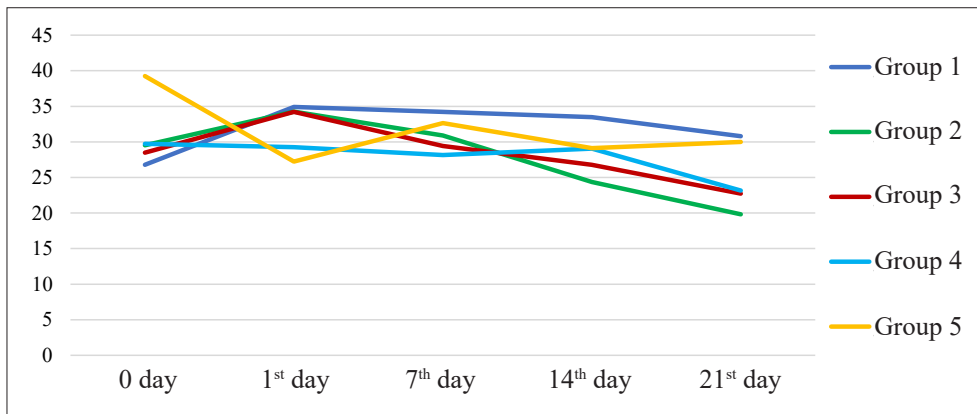


Figure 10. The graphic evaluation of the albumin

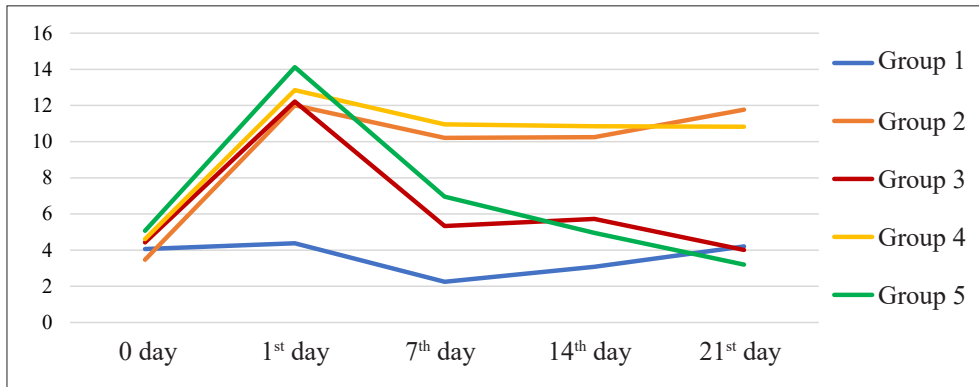


Figure 11. The graphic evaluation of bilirubin

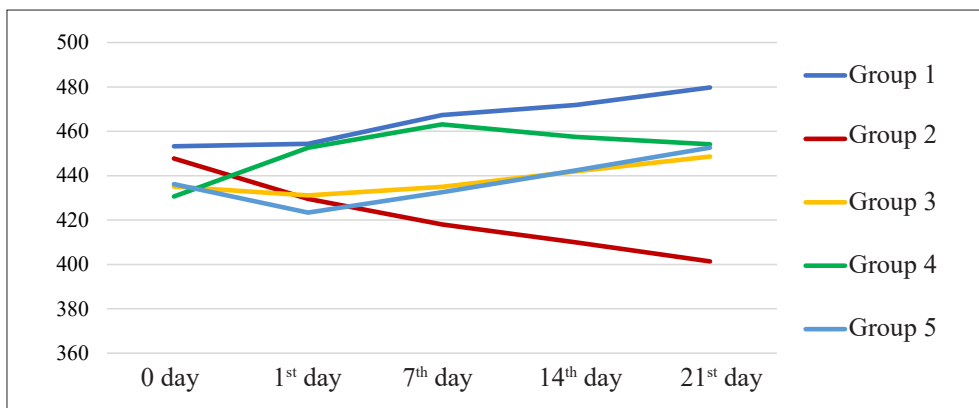


Figure 12. The graphic evaluation of weight

Evaluation of histological preparations. At the preparation staining with Hematoxylin and Eosin the second group preparations were compared with those in the group 3 (Fig. 13, 14), and the group 4 – after hepatic

damage with TAA with the group 5 (Fig. 15, 16). The liver tissue after resection in the group 2 is incompact and congested at several sites compared to the group 3.

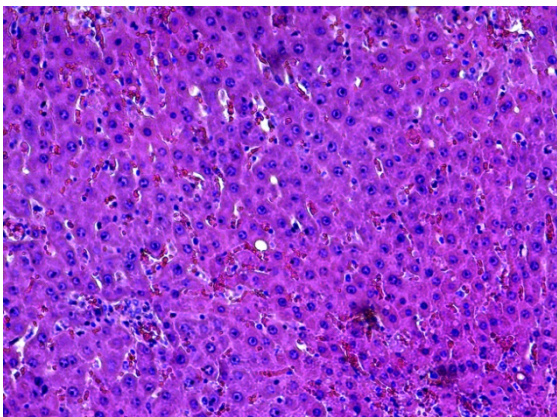


Figure 13. Liver tissue (group 2) magnification 100x

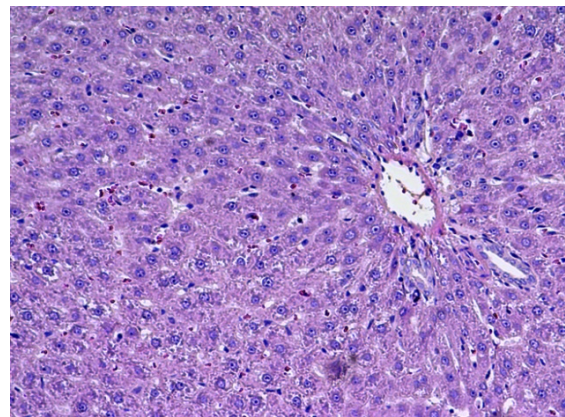


Figure 14. Liver tissue (group 3) 100x

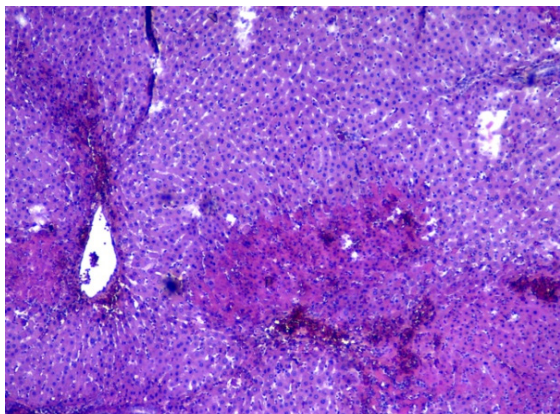


Figure 15. Liver tissue (group 4) magnification 40x

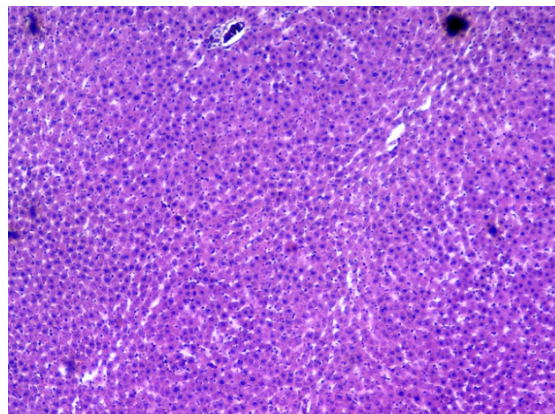


Figure 16. Liver tissue (group 5) 40x

The evidence of the presence and transfer of stem cells using the electron microscope. After administration of mesenchymal stem cells to experimental animals, we observed the penetration of these cells and their subsequent growth. The mesenchymal stem cells (MSC)

inoculated into the damaged liver transferred from the site of administration through the vena portae to all areas of the liver. The nuclei of all cells present in the liver are blue-shining, and the MSCs nuclei are red shining (Fig. 17, 18).

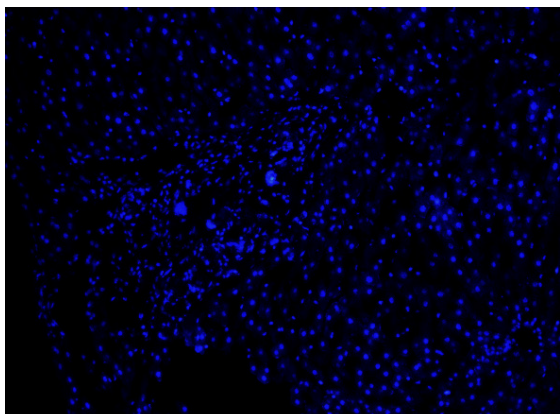


Figure 17. Displayed nuclei of all cells of the liver

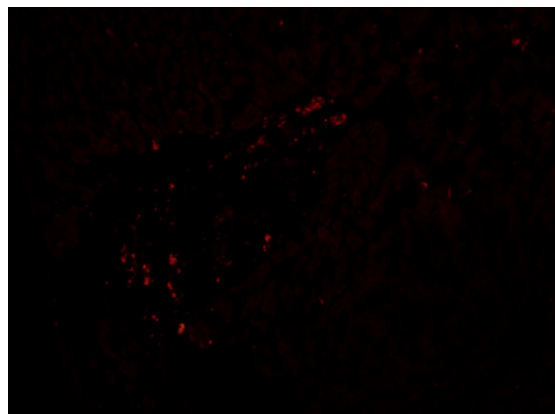


Figure 18. Nuclei of MSCs in the liver

The liver has permanently attracted people's attention, the Greeks have already recognized the inexhaustible feature of the liver-regeneration, whose principles have still being studied [14]. The liver has an irreplaceable role in the living organism. Like other organs, it is subject to various diseases: genetic, traumatic, inflammatory, and cancerous diseases. There are several types of tumours in the liver, both benign and malignant. The most appropriate healing method for liver tumours, including carcinomas, is radical resection of the liver. Hepatic carcinoma often occurs in the cirrhotic liver, thus the functional capacity of the left cirrhotic remains of the liver is significantly reduced that increases the mortality and shorten the patient survival time [15]. A serious problem with liver cancer is therefore the possibility of performing radical surgical resection and leaving sufficient functional parenchyma of the liver. To support the liver regeneration after extensive resections, the possibility of treatment with the application of mesenchymal stem cells is being investigated [9; 16].

Stem cells are primarily undifferentiated cells capable of self-regeneration and differentiation to other, more specialized cell types. In the experiment, mesenchymal stem cells (MSCs) were applied to experimental animals. The bone marrow mesenchymal stem cells with differentiation potential to four lineages (mesenchymal and vascular smooth muscle lineages), and stromal and immunomodulatory capacities, the stem cell attributes are multipotentiality, self-renewal, tissue regeneration, population heterogeneity, plasticity. These stem cells are relatively easy to isolate, the source for their isolation is well available, the cells proliferate well in the cultures, but the resulting population is considerably heterogeneous [17; 18]. The experimental studies on mice by M. Kaibori et al. [10] attempted to stimulate the liver regeneration by transplanting MSCs taken from the bone marrow of mice. Autologous transplantation of MSCs has shown a great promise to improve the tissue regeneration in various acute and chronic diseases. The treatment has shown improvement in the liver regeneration in acute

and chronic forms of the disease in both preclinical studies and pilot clinical trials. The stem cell therapy can provide effective treatment and facilitate regeneration after resection of the liver, or before resection. The study by M. Kaibori et al. 2012 [10] explained the important role of stem cells in the liver regeneration after extensive resection of the liver.

CONCLUSIONS

Based on the available literature and various clinical and preclinical studies, we have also progressed in our experiment. The stimulation effect of MSCs on the liver regeneration was observed based on the laboratory values of alanine aminotransferase (ALT), bilirubin, and albumin, control of the experimental animal weight, and histology. The results obtained were identical to those used in the literature. A statistically significant decrease in the

ALT ($p < 0.001$) and bilirubin ($p < 0.001$) values in the groups of the rats treated with stem cells was observed and compared to the groups without stem cell transplantation. As well, a statistically significant increase in albumin in the groups after application of mesenchymal stem cells was found, $p < 0.001$. The results of the experiment lead to the conclusion that mesenchymal stem cells have a significant effect on the liver regeneration after its damage. The electron microscopy revealed the transfer of mesenchymal stem cells from the application site to the site of their action and differentiation. In the future, it is worthwhile to examine the other properties of stem cells, to continue experimental studies and then to apply this knowledge to the medical practice. Stem cells represent a major advance in the treatment of liver tumours and stimulation of the liver regeneration.

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**Стимуляція регенерації печінки за допомогою
мезенхімальних стовбурових клітин кісткового мозку**
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Анотація. Основною метою даного експерименту було довести вплив мезенхімальних стовбурових клітин кісткового мозку (МСК) на стимуляцію регенерації печінки. Приділено увагу адаптації стовбурових клітин до нового середовища та їх перенесення в анатомічні структури. Експеримент включав 40 самців щурів Спрег-Доулі (СД) віком від 10 до 12 тижнів. Біомоделі були розділені на п'ять груп у однаковій кількості (n=8). Група 1 складалася з контрольної проби з восьми здорових щурів. 2 група складалася з восьми щурів після резекції печінки без застосування МСК. 3 група була після резекції печінки та застосування МСК. Група 4 – після ураження печінки індукують тіоацетамідом (ТАА), без трансплантації МСК. 5 група була після хімічного ураження печінки введенням ТАА та трансплантацією МСК. Процес стимуляції печінки спостерігали на підставі лабораторних показників аланінамінотрансферази (АЛТ), альбуміну та білірубіну. Також порівнювали вагу щурів у кожній групі. Тварин забивали через 1 день, 7 днів, 14 днів і 21 день. У нашому експерименті було виявлено статистично значуще зниження рівня АЛТ ($P \leq 0,001$) і білірубіну ($P \leq 0,001$) у групах 3 і 5 (лікування МСК) порівняно з групами без МСК (групи 2 і 4). Підвищення рівня альбуміну в групах 3 і 5 було статистично значущим. Результати цього експерименту привели до висновку, що трансплантація МСК має важливий ефект для лікування та стимуляції регенерації печінки після травми. Введення МСК може бути надзвичайно корисним у ряді клінічних застосувань у лікуванні пухлин печінки. Це дозволить виконати обширну резекцію печінки без ризику печінкової недостатності

Ключові слова: стовбурові клітини, тіоацетамід, резекція печінки, регенерація печінки

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Improving the Efficiency of Distributed Water Supply Systems by Means of an Adjustable Electric Drive

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Abstract. The water supply of the pumping station must meet the needs of the consumer which change during the day. Therefore, its performance needs to be adjusted. Any deviation of the pump unit's performance from the nominal value leads to additional energy costs. Under such conditions, great importance is paid to optimising the operation of electric drives of the water supply pumping station. To regulate the performance of a pumping station, it is often resorted to changing the number of operating pumping units, the engines of which are started directly from the electrical network. Medium-and high-power engines are subject to technical restrictions for a direct start, which are supplemented by the need to maintain pauses between starts. Therefore, when ensuring the desired value of pumping station performance, it is very important to consider the features of starting pump engines. Control systems are widely used in the field of electric drive and water supply. It is in these areas that the efficiency of the control system depends on the amount of electricity that will be consumed by the technological process or the reliability of its operation. It is known that pumps account for about half of all energy produced. Therefore, the issue of effective control systems is particularly relevant in the field of water supply. The purpose of this study is to increase the reliability and efficiency of the water supply system by considering the distribution properties of the pipeline network when controlling electric pump drives, which will allow coordinating the operation of the pumping station, the pipeline network, and the consumer. To achieve this purpose, the study was conducted to assess the impact of the distribution and length of the pipeline network. The system of water supply and distribution is analysed, what criteria affect the correct performance of work and what problems may arise during operation for a long period of time are investigated. Ways to optimise the operation of pumping stations to increase their energy efficiency and cost-effectiveness of installations are investigated. The main reasons for the expediency of using an adjustable electric drive to control pumping units are considered

Keywords: water supply, water supply system, electric pump station drives, mathematical models of electric drive, pumps



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INTRODUCTION

The design of automatic control devices has been studied by many scientists [1-4]. Among them, the works of I.A. Vishnegorodsky should be highlighted, who became the founder of the theory of automatic devices in the 19th century [5; 6]. The scientist determined that the machine and the regulator form a single dynamic system that has certain stability indicators (he developed the theory of control stability) and the most important patterns of regulation based on the feedback principle [7-9]. Nowadays, there is a rapid development and active use of micro-processor technology in water supply systems. It allows linking all information flows between all elements of the water supply system. Up-to-date information about the progress of the technological process is sent to the operator very quickly. Similarly, the operator can influence the technological process by sending control signals. In such systems, the state of technological objects is measured, monitored, and regulated [9; 10].

Automation in water supply processes has allowed increasing productivity by 20 times and reduce operating costs by 10 times. There are many difficulties in water supply processes. The main problems related to water supply can be formulated in two phrases: there is an abundance of water where it is not needed so much, and there is no water where it is needed. One of the serious problems on the way to full automation of the water supply process was the distribution of these systems in space and time. Therefore, the thesis proposes to develop the ideas of well-known scientists on effective management of distributed systems, and implement them on water supply systems. Notably, the efficiency of water supply systems is mainly determined by the energy and hydraulic aspect. The paper will focus specifically on energy.

The purpose of the study is to increase the reliability and efficiency of the water supply system by considering the distribution properties of the pipeline network when controlling electric pump drives, which will allow coordinating the operation of the pumping station, the pipeline network, and the consumer. The goal is achieved by solving the following tasks: to analyse literature sources on the subject of paper; to identify the main parameters of the water supply system, on which the reliability and efficiency of its operation depend; to assess the impact of the length and distribution of the pipeline network of the water supply system on the efficiency of electric drives of the pumping station; to offer solutions to improve the operation of water supply systems precisely by considering their distribution; to model the operation of the water supply system in different modes. The object of research is the process of controlling electric drives of a pumping station. The subject of the research is mathematical models of electric drives, pumps, and water supply systems.

MATERIALS AND METHODS

The paper uses methods of probability theory, mathematical statistics (statistical linearisation, processing of experimental results, testing statistical hypotheses), operations research (mathematical programming, graph theory), automatic control theory, theory of ordinary differential equations, theory of experiment planning, modelling on a computer.

Due to an increase in water consumption, it is necessary to develop new methods for designing and managing water supply systems. Such methods should have the following functions: to reduce unproductive resource losses as much as possible by analysing the operating modes of water delivery systems and increase the efficiency of decision-making during their operation and development; to increase the durability and survivability of water delivery systems by optimising them using simulation modelling; to test options for possible solutions for managing the water delivery system during its operation using simulation parametric and structural modelling; to quickly identify the current state of the water delivery system depending on the position of shut-off and control devices, etc., graphically interpret and visualise on the monitor screen (static identification), identify changes in the current state of the water delivery depending on changes in the position of one or a group of regulating units (dynamic identification); reduce losses from accidents in the water distribution network due to more rapid localisation of the emergency zone, as well as reasonable interaction with dispatchers of operation services of other engineering systems of the city (for example, with heat supply and hot water supply systems, power supply).

The most important role in the rational use of water resources in the region is played by the water delivery system, which is directly related to the operation of pumping stations, reservoirs, and the city's water supply network. Water networks belong to the class of continuously evolving systems, the development of which is carried out both in time and space. The main functional purpose of the water delivery system is to provide consumers with the target product – water of the required quantity and quality and under a given pressure with minimal head losses on the networks. Water consumption is, as a rule, a non-stationary stochastic process containing determined monotonically increasing trends and periodic components, the parameters of which change over time [11].

Often, when analysing water supply systems, there is not enough information about their condition. This leads to a decrease in the efficiency of the water supply and distribution management system. There are different approaches to improving the performance indicator. The conventional technical approach is based on minimising cost factors with some simplified restrictions.

Thus, it is usually considered optimal to increase the efficiency of the pumping station system, the efficiency of modes on water networks or water disinfection, which ensures the safety of water supply to the population. In the practice of operation, insufficient attention is paid to the hydrodynamic characteristics of the water delivery system. Therewith, they play an important role in evaluating a balanced integrated approach to rational management of the water supply system.

Modern water supply management systems cannot be considered effective if they do not have information technology. As a rule, it takes about 10 years to implement information systems in water supply companies. Usually, those who implement an automated process control system can only partially discuss the results of implementing automated control systems in blocks. It is known that in modern water supply systems, the following rules must be observed: it is necessary to ensure a sufficient flow of water with the necessary head and satisfactory water quality. The criteria for the quality of water network operation in practice are compliance with two conditions: the pressure at each water supply point must be between the minimum and maximum permissible values of 20 and 60 m H₂O. Accordingly, the head fluctuation in the network should not exceed 45-50% of the maximum allowable head. Controlling the flow rate in its pipelines is extremely important since the impact pressure during a water hammer changes directly in proportion to the nominal value of the average speed in the pipe. It is this indicator that allows distributing water flows in pipelines and equalise water consumption in different sections of the pipeline.

RESULTS AND DISCUSSION

Development of a block diagram of the water flow system in water supply networks

The main purpose of the operation of the water supply system is to provide consumers with uninterrupted water supply in exact accordance with their current needs. Therewith, this goal should be achieved with the highest possible efficiency. There are many sources and ways to improve the efficiency of the water supply system. Most of them can be unambiguously attributed to one of three groups: ways to improve the efficiency of water supply sources; ways to improve the efficiency of pipeline networks; ways to improve the efficiency of water supply systems [12].

Improving the efficiency of flow control systems will be achieved by reducing the total number of measuring instruments and control bodies of the control system and improving the efficiency of flow control. These points will improve the efficiency of pipeline networks and water supply systems. To achieve this purpose, it is necessary to formulate the concept of efficiency of flow control systems, determine what it depends on, and

investigate how it can be achieved using mathematical modelling [13].

The water supply system as an object of control in the process of its functioning interacts simultaneously with two systems: the external environment and the water supply control system. The external environment, acting on it, leads to a violation of its hydraulic and thermal conditions, which accordingly affects the quality of customer provision. The main task of the water supply control system is to compensate the influence of the external environment to maintain the necessary hydraulic and thermal conditions, while the task of the flow distribution control system as an integral part of the control system is to ensure optimal distribution of water between consumers, which is achieved by controlling the flow distribution in the pipeline network.

The mechanism of interaction between the water supply system and the external environment is quite complex, which is explained by the large number and complex nature of external disturbances due to their physical nature, so it is not possible to create a simple mathematical model of the relationship between the water supply system and the external environment. Well-known mathematical models are partial in nature and in most cases turn out to be too complex for their direct application in the mathematical model of the flow control system. In this regard, the authors will continue to assume that external disturbances are not directly controlled and their impact can only be judged by changes in the parameters of the water supply system.

Let us divide the vector of parameters of the water supply system R into parameters of elements D and parameters of the state (mode) Z . The parameters of elements D include those parameters of the water supply system that are not affected by external disturbances and remain almost unchanged throughout the entire time of operation, or change very slowly (coefficients of hydraulic and thermal resistance of pipelines, flow characteristics of pumps, parameters of control bodies, etc.). Let us assume that the parameters of the elements are known, respectively, they will be included in mathematical models as constants, so in further mathematical calculations, the authors will not select the vector of parameters of the elements D separately. The parameters of the Z state (flow rates, heads, temperatures of the coolant, variable coefficients of hydraulic and thermal resistance of consumers), on the contrary, constantly change under the influence of external disturbances, and they determine the state of flow distribution. In the future, when referring to flow distribution, the authors will keep in mind the parameters of the Z state.

The flow control system is a complex system that consists of four subsystems (Fig. 1): collecting and transmitting information, processing information, developing control influence, and implementing control influence.

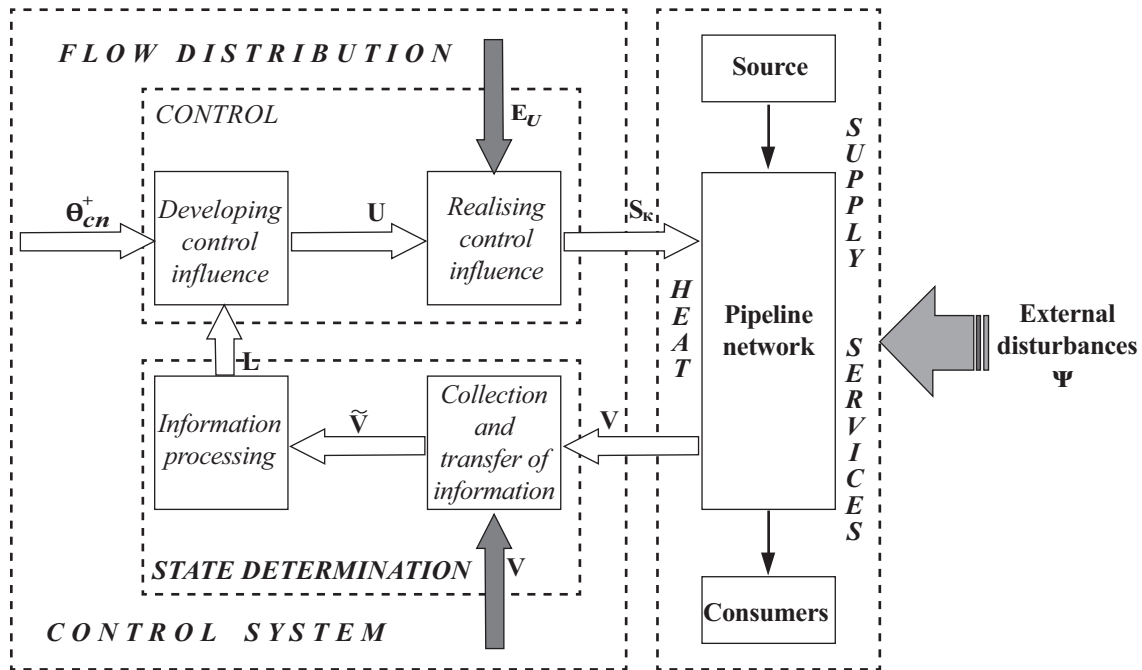


Figure 1. Block diagram of the flow control system

The presented scheme is closely intertwined with the system of automation and control of water supply systems [14]. The automated process control system of a pumping station is a comprehensive solution to the problem of managing the water supply of pumping stations of industrial enterprises, as well as public utilities based on the introduction of advanced energy-saving technologies. The implementation of automated control systems can be carried out both at newly designed pumping stations and at existing ones, considering existing equipment. The essence of the solution is to manage the water flow.

Purpose of the system: automatic maintenance of the set water pressure in the outlet water supply; remote control of the operation of pumps and valves; visualisation of the technological process at the operator's workplace; collection and processing of statistical data on the volume of rolled water and the status of pumping units; ensuring the optimal mode of water supply to the outlet water supply; improving the reliability of pumping station equipment; extending the life of electric motors of pumps; reducing energy costs.

The system is a three-level hardware and software complex, namely: the level of control of technological units (pressure and water flow sensors, adjustable and unregulated electric drive of pumps and valves); the level of control of the technological process (programmable logic controller); the level of operational and administrative control (operator's workstation based on a personal computer).

In urban water supply systems, water supply failures often occur. There is a pressure drop or the pipe becomes

clogged, which makes the flow weaker. In addition, considering the current trend towards urbanisation, expansion of cities and the growth of the population in cities, the issue of increasing the capacity of water supply and increasing the capacity of pumping stations becomes relevant. For remote consumers, the issue of ensuring a sufficient level of pressure in the pipeline is acute. Commonly, the pressure on the outskirts of a locality is less than the required values. Therefore, for the water supply of such places, water supply stations are used in addition to the centralised water supply system. The pumping station consists of pumping units and communications. The appearance of the engine room of the pumping station is shown in Figure 2.

It is such a station that stabilises the pressure and its indicators become constant. And most importantly, an uninterrupted supply of the necessary amount of water for any needs is achieved. A modern pumping station should operate in a fully automated mode and does not require specialised regular maintenance. It can be used for the following areas: fire water supply; industrial; private. Modern pump automation systems allow implementing closed systems for stabilising water pressure in the pipeline. For this purpose, the centrifugal pump is equipped with an adjustable alternating current electric drive. Changing the speed of rotation of the latter is performed by the frequency method, that is, by changing the frequency to the supply voltage of the drive motor. To maintain the pressure, a regulator and feedback with a pressure sensor are used.

Let us build a block diagram of the water supply system using a pumping station and feedback on the water pressure in the pipeline (Fig. 3).



Figure 2. Pumping station

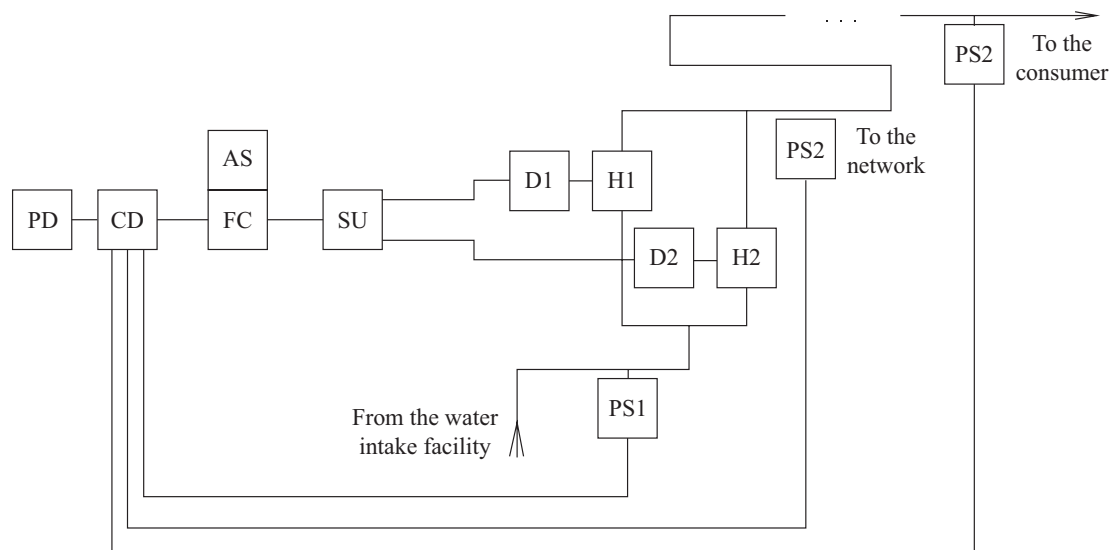


Figure 3. Block diagram of a distributed water supply system

Figure 3 shows: D1, D2 – alternating current drive motors; H1, H2 – centrifugal pumps; PS1, PS2; PS3 – water pressure sensors at the station inlet and outlet after the station and near the end user; PSN – power supply network; AS – automatic switch; PD – pushing device; CD – control device; FC – frequency converter; SU – switching unit;

The pressure sensor PS1 detects the pressure value in the pressure line of the water tower and converts it into an electrical signal of a certain value. The pumping station should only be switched on when the pressure at the station inlet is less than the required pressure value at the dictating point of the consumer. The PS2 pressure sensor allows monitoring the pressure level

near the consumer. It is to this signal that the electric drive of the pump unit will respond. That is, when the water pressure near the consumer is insufficient, the electric drive should work faster and vice versa, at high pressure near the consumer, the pump unit should slow down. The CT3 pressure sensor allows analysing system's response to various control actions. Based on the results of this analysis, it is possible to ensure rational control of electric pump drives. The essence of which is that at the input of the water supply system, for example, there is no need to supply a lot of water since at its exit there is still no direct reaction from the supplied amount of water. At the outlet of the pipeline, the water pressure will change according to a certain law and the

established value of the output pressure will be set only after passing the transition process. The duration of the transition process will depend on the parameters of the pipeline, its length, material, etc. Therefore, during this time, the pumping station can pump the maximum amount of water, or it can supply a certain permissible value. As a result, there will be an overspend of energy and more intensive use of the pipeline resource than with measured operation of the equipment.

Improving the efficiency of distributed water supply systems

The main condition for water transportation is to ensure its quality, flow rate, and pressure. When transporting water from air conditioning systems in main pipelines, reactions occur between water and the pipeline material. As the water temperature increases, chemical and biological processes in the water increase, and its quality changes the longer the water is in the pipeline system. This also affects the appearance of irregularities (roughness) on the inner surface of the water pipeline.

When designing water pipes, it is considered that the movement of the water flow will be turbulent and only in some cases transition modes may occur in the water pipes. The calculation of steel main water pipes of large diameters is based on the formula proposed by F.A. Shevelev for calculating the coefficient of hydraulic resistance λ for automodel turbulent water flow modes:

$$\lambda = \frac{0.021}{d^{0.3}} \quad (1)$$

where d is the diameter of the water supply system, m .

During long-term operation of water pipelines, the capacity of metal pipelines is considerably reduced due to internal corrosion and inlay. During operation, the hydraulic resistances of pipelines increase by 2-7 times or more compared to the initial values. They depend on the diameter and material of the pipes, the quality indicators of the transported water, the operating conditions and the service life of the pipeline. The most complex and time-consuming operation when calculating the hydraulic resistances of existing water supply lines is to determine the flow rate of water passing through the pipeline. The volumetric method is quite accurate:

$$Q = \frac{W}{t} \quad (2)$$

where W is the tank volume, m^3 ; t – time it takes for the tank to fill or empty, s .

If there are a large number of network sections, such work is very cumbersome. When examining the current water delivery system, it is advisable to test only the characteristic sections of the network, grouping them depending on the material and diameter of pipes, as well as on the conditions and terms of their operation. In hot water supply systems, the operating conditions of pipelines are different. The water temperature there should reach 55-60°C. Under such conditions, deposits

on the inner surface of pipelines increase and the live cross-section can considerably decrease. Pipeline calculations should take into account changes in pipe parameters, including overgrowth of pipelines as a result of corrosion and precipitation of suspended calcium carbonate particles from water.

In foreign practice, the Colebrook formula is widely used for calculating water pipes, which determines the value of the hydraulic resistance coefficient depending on the numerical parameter of roughness – equivalent roughness:

$$\frac{1}{\sqrt{\lambda}} = -2 \lg \left[\frac{k}{3.7D} + \frac{2.51}{Re \sqrt{\lambda}} \right] \quad (3)$$

where k is the equivalent roughness; D is the inner diameter of the pipe; Re is the Reynolds number.

Distribution of hydraulic parameters in the water supply and distribution system during normal and emergency operating modes Existing methods for calculating flow distribution allow determining the water pressure at nodes, water flow rates at sites with specified network parameters, node flow rates, and pipe types (diameter and material). Hydraulic linking is based on Kirchhoff's laws, supplemented by dependences for hydraulic head losses on flow rates in the network section. Such models are deterministic and do not consider the uncertainty of the initial data, the main contribution to which is made by the stochastic nature of water consumption. Stochasticity is characterised by an unregulated random process of water intake by consumers, wear and aging processes, as well as accidents associated with equipment failure.

When modelling the hydraulic modes of water supply networks in conditions of emergency shutdowns of individual sections, it is necessary to consider the reduction in water consumption caused by a decrease in heads in a number of consumers. This means that water stops flowing to the upper floors of residential buildings. It can be assumed that under pressure from consumers there is H_i equal, or greater than necessary $H_{i,req}$, water consumption Q_i is equal to the standard value of $Q_{i,req}$, and when the pressure decreases, no water consumption decreases according to the quadratic law:

$$Q_i = \begin{cases} Q_{i,req} & \text{at } H_i \geq H_{i,req} \\ Q_{i,req} \cdot \sqrt{H_i/H_{i,req}} & \text{at } H_{i,crit} \leq H_i \leq H_{i,req} \\ 0 & \text{at } H_i \leq H_{i,crit} \end{cases} \quad (4)$$

where $H_{i,crit}$ – critical head corresponding to the complete cessation of water draw-off, which can be assumed to be zero. Thus, the device through which water is taken in the i node at head $H_i \geq H_{i,req}$ operates in control mode, and when the pressure is below this threshold – in throttling mode.

The water supply and distribution system is a renewable object, the operability of which, in the event of a failure, is subject to restoration (in the future, the

processes of failures and restoration of only sections of water supply lines will be considered). The process of functioning of the restored element is an alternation of periods: serviceable operation, failure and recovery, and again a period of serviceable operation. The duration of repairs depends on a number of operations, which

are determined by various reasons, and are considered random variables. Figure 4 shows the time series of water use in a residential building. The figure shows that water extraction has the form of random periodic fluctuations. At some points in time, it reaches zero values, which corresponds to negative states.

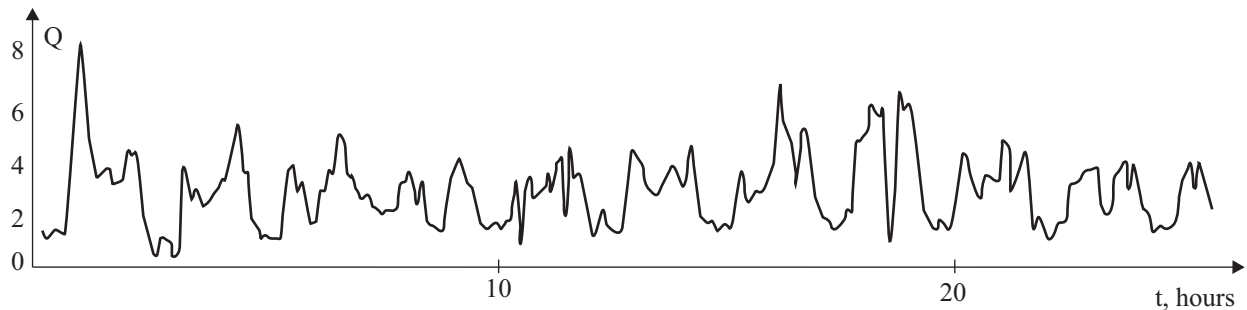


Figure 4. Measurements of water use during the day

The recovery process lasts several hours, during which water consumption is constantly changing in accordance with daily fluctuations and stochasticity of the process. Thus, when disconnecting sections, in some cases, nodes will fail due to a lack of heads in them, in other cases, with a decrease in water consumption, there will be no node failure. To reduce negative phenomena in the post-accident period, the parameters of the water feeder can be controlled, for example, by turning on additional pumps.

As a result, the authors come to the following calculation sequence:

1. At the initial point in time, all sections are considered serviceable. By simulating, arrays of failure and recovery times of each section are formed. The time of the nearest failure is determined, which is converted to the calendar date and hour of the day. They are used to find the number of the water consumption schedule (if there are several of them) and the estimated time. According to another software implementation of the algorithm, the most unfavourable case is selected – the hour with the maximum consumption during the day.

2. A random vector of water consumption is simulated and a hydraulic calculation of the system is performed when the emergency section is disconnected according to the scheme with non-fixed selections. The possibility of switching on additional pumps is determined.

3. The nodes with less than the required pressures are identified and the results are saved in the output file.

4. The transition to the next time of day is conducted and the time after the accident is compared with the recovery time. If the repair continues, the water consumption vector is played out for the new hour and the network is linked. The calculation is repeated until the end of the accident elimination time, after which the site is considered working and a new failure and recovery time is determined for it.

5. The time of the nearest accident is simulated and the calculation until the end of the simulation is repeated.

6. The received data is processed, as a result of which the total failure time for the simulation period and the contribution of accidents of individual sections to the failure of the selected node are determined for each node.

When developing the algorithm, the following assumptions are made: site failures are independent of each other; when simulating nodal costs, changes in the nature of water consumption at the time of the accident associated with the redistribution of water analysis time are not considered; nodal costs obey the normal distribution law.

The process of operational management of the water delivery system in cities is considered as a controlled process of joint operation of pumping stations, water network, reservoir, and their components. The presence of the main components in water consumption processes, such as the harmonic component and random noise, leads to the need to build a two-level control scheme for the current management of the existing network of the water delivery system. This scheme includes planning of water transportation and distribution modes, which allows purposefully tracking harmonic trends by changing the structure and parameters of the existing network; operational management that eliminates unwanted pressure changes at the dictating point of the network. The need for a certain amount of time to implement control actions at the considered control stages requires the use of a discrete control method at each of these stages. Therefore, the control interval is divided into discretion (*Quanta*), which are determined both by the accuracy of approximation of the corresponding components (harmonic, noise) of water consumption processes and by the time of control implementation at each stage. The discreteness of management allows presenting this process at each stage in the form of a sequential multi-step decision-making procedure. The effectiveness of any system is related to the qualitative and quantitative goals of managing this system. The main qualitative goal of managing the system in question is to implement the technology of water transportation and distribution.

For the quantitative characterisation of achieving the purpose, the management criterion is used, which in this case can acquire only two values: one (if the purpose is achieved, the consumer has water at any highest point) and zero (otherwise, the consumer does not have water). Qualitative goals are strategic and are used at the highest level of the entire system management hierarchy, as they are related to providing water to all consumers. The apparent simplicity of such a control criterion is deceptive since the functional dependence of the criterion on the controlled parameters can be quite complex.

Suppose P_j and P_j^+ – current and minimum allowable pressure in the j node, respectively. Then the total excess heads at time t will be equal to:

$$y(t) = \sum_{j \in V} (P_j(t) - P_j^+) = \sum_{j=1}^v (P_j(t) - P_j^+) \quad (5)$$

where V is the set of vertices of the network graph; v – the number of its vertices.

The management criterion is key in understanding many problems that arise in the organisation of rational functioning of water delivery. Under normal conditions of optimal operation of the water delivery system, the current pressure P_j in the j node should always be greater than or equal to P_j^+ . Ideally, the pressure of consumers should be the minimum allowable P_j^+ , but from the physical essence of the water delivery system, it follows that the pressure at the pumping station should always be higher than in any other node of the water network. On the other hand, it is known that excess of the current pressure over the standard one leads to undesirable consequences: an increase in electricity consumption; increases water leakage in the internal networks of buildings (unproductive water consumption); increases the probability of damage to the water network, which in turn leads to an increase in the probability of damage from an accident, etc. Evaluation of this criterion over a period of time $[0, T]$ allows judging the effective functioning of the water delivery subsystem from the standpoint of fulfilling the latter's main functional purpose. Change in piezometric height, and therefore pressure P_j (The authors will sometimes call it the free head at a point) at each vertex of the graph (node connection diagram) of the water delivery subsystem at a given time interval $[0, T]$ the authors will characterise it with a functional of the form:

$$Z_j = \frac{1}{T} \int_0^T \varphi(P_j(t)) dt \quad (6)$$

where $P_j(t)$ – a random process of changing the free pressure value in the j node of the water delivery subsystem;

$$\varphi_j(t) = \varphi(P_j(t)) = \begin{cases} 1, & \text{at } P_j(t) \geq P_j^+ \\ 0, & \text{at } P_j(t) < P_j^+ \end{cases} \quad (7)$$

Functionality characterises the relative time during which the water delivery subsystem performs its functional purpose in the j node of the network, that is, the j -consumer is provided with water on all floors of a residential building in any node. If information about the value of the free head in the j node was received at discrete time points $t, t + 1$, then in this case the expression can be approximately replaced by an integral sum:

$$Z_j = \frac{1}{T} \sum_{k=1}^T \varphi(P_{jk}) \Delta t_k, \quad (j \in V) \quad (8)$$

where k is the discreteness of the time interval equal to the number t ; T is the time interval (usually in practice $T=24$ hours). The quality of functioning of the water delivery system over the time interval $[0, T]$ in the simplest case can be characterised by a function of the form.

$$Z = \frac{1}{v} \sum_{j \in V} Z_j \quad (9)$$

where V is the set of nodes; v – number of nodes.

As is evident, the values of these criteria range from 0 to 1. Quantitative management goals are to reduce (or increase) the value of certain criteria that reflect the operating modes of the managed object. As such a criterion, quite often in water supply networks, a function is used trying to find its minimum. Another common criterion for the efficiency of water delivery functioning is energy consumption at time t :

$$y(t) = \sum_{j \in L} \frac{h_j^{(a)}(t) q_j(t)}{102 \eta_j} \quad (10)$$

where $h_j^{(a)}, q_j, \eta_j$ – head loss, the flow rate at the j pumping station and its efficiency, respectively; L – set of pumping stations. Integral estimation of energy consumption over the time interval $[0, T]$:

$$Z = \int_0^T y(t) dt \quad (11)$$

or with a discrete method of capturing information:

$$Z = \sum_0^T y_j \Delta t_j \quad (12)$$

The authors will focus on a number of other criteria for the functioning of water delivery that have become widespread in practice. Maximum excess pressure at time t (it is dictated from the conditions of the number of storeys of buildings and the prevention of free head in the distribution network pipelines of more than 60 m of water column):

$$Z(t) = \max_{j \in N} P_j(t) \quad (13)$$

This criterion characterises “tight spots” in the water delivery system, especially in the mode of minimal water consumption, which can lead to damage to the water network and unproductive water consumption in the intra-house network. Here N is the set of water consumers. Total instant water consumption:

$$y_1(t) = \sum_{j \in L} q_j(t) = \sum_{i \in N} q_i(t) \quad (14)$$

The integral estimate of water consumption over a time interval $[0, T]$ is calculated by analogy with the expressions, namely:

$$Z_1 = \int_0^T y_1(t) dt \quad (15)$$

or, if the incoming information is discrete:

$$Z_1 = \sum_{j=1}^T y_{1j} \Delta t_j \quad (16)$$

Estimation of total leakage in water supply systems:

$$y_2 = \sum_{j \in N} A(P_j - P_j^+) q_j \quad (17)$$

where A is the coefficient of unproductive water losses per unit pressure change. The main task of operational management is to ensure that the water delivery system fulfils its intended purpose. Managed variables for these networks are the parameters and structures of individual subsystems. Parameters and structure can be controlled on active elements (pumping stations) and distribution networks. Changes in the parameters and structure of consumers can be judged by changes in the parameters of water consumption processes. Thus, the task of operational management of the water delivery system is to compensate for changes in the structure

and parameters of managed subsystems by changing the structure and parameters of consumers. Moreover, compensation for these changes should be carried out by minimising some functional losses in energy, cost, or reliability terms, while observing the corresponding set of restrictions.

The structure of the process of operational management of flow distribution in water supply networks can be presented in the form of two main stages or levels of management: 1) operational planning of flow distribution in the water supply network, considering the prevailing influence of some criterion on this planning period (minimum operating costs, reliable water supply to consumers, ensuring the criterion of quality of functioning according to the formula, which should be equal to one); 2) pressure stabilisation at dictating points in a given range. Solving the problem of operational management at each of these levels, as a rule, is spaced in time and space, requires a different amount and nature of operational information, the presence of mathematical models describing the object of management, various criteria and methods for solving management problems.

The authors will focus on the main tasks of water distribution, which are most widely used in solving the problems of designing and developing water supply networks. In the design process, the problem arises of choosing the optimal operating mode of pumping stations when they work together on the water supply network. Known: network structure; nodal flow rates (hence the total flow of water supplied to the network by pumping stations); pipeline diameters; length of main sections; geodetic marks; minimum allowable free heads at network nodes; number of pumping stations operating on the network, $l \geq 1$. For the mathematical formulation of this problem, let us focus in more detail on the mathematical model of steady-state water distribution in the water supply network (Fig. 5).

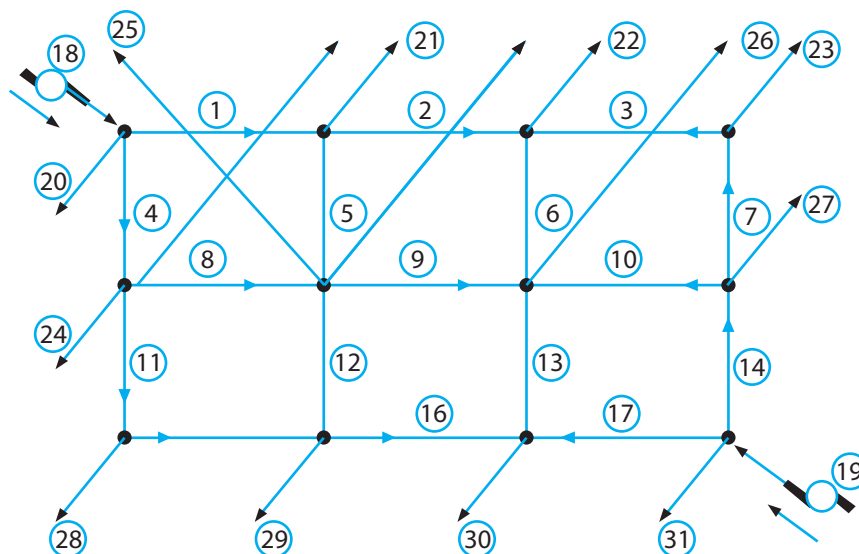


Figure 5. Example of a water supply network and illustration of its division into three disjoint subsets

Let the set E of arcs of the water supply network graph consist of three subsets: real arcs M corresponding to pipeline sections; fictitious active arcs L corresponding to network inputs (pumping stations); fictitious passive arcs N corresponding to network outputs (consumers).

$$M = \{1, \dots, 17\}, m = 17 \quad (18)$$

$$L = \{18, 19\}, l = 12 \quad (19)$$

$$N = \{20, \dots, 31\}, n = 12 \quad (20)$$

$$E = M \cup L \cup N \quad (21)$$

$$E = \{1, \dots, 31\}, e = 31 \quad (22)$$

Let any vertex of the graph be an input or output (water supply or intake in the water network). The zero vertex is the initial (input) for the pumping station and the final vertex is used for water supply or intake to consumers' water networks (fictitious).

$$h_j = -P_j, (j \in L) \quad (23)$$

$$h_j = P_j, (j \in N) \quad (24)$$

Each of the areas $j (j \in L \cup N)$ will be characterised with two values q_j and P_j and called the input nodal flow rate and pressure if $j \in L$, or the initial nodal flow rate and pressure, if $j \in N$. In other words, the node number matches the section number of the corresponding network input or output. If on plot $j (j \in L \cup N)$ the pressure is set, then this section will be considered as the source of the pressure difference $h_j = -P_j (j \in L)$ and $h_j = P_j (j \in N)$ with internal resistance $S_j = 0$. If a flow rate is set in this section, then it will be considered a current source q_j with an internal resistance $S_j = \infty$.

Here is a comparison with the formula for pressure losses in the pipeline:

$$h_j = S_j q_j^n \quad (25)$$

where S_j is hydraulic resistance of the site.

For the actual section of the pipeline, the following ratio will be fair:

$$h_j = S_j \operatorname{sgn}(q_j) |q_j|^{X_j} (j \in M) \quad (26)$$

Thus, a mathematical model of a water supply system with many nodes will have the form:

$$f_r = S_r \operatorname{sgn} q_r |q_r|^{X_r} + h_r^{(r)} + \sum_{i \in M_1} b_{1ri} (S_i \operatorname{sgn} q_i |q_i|^{X_i} + h_i^{(r)}) - \sum_{i \in L_1} b_{1ri} P_i + \sum_{i \in N_1} b_{1ri} P_i = 0 \quad (r \in M_2) \quad (27)$$

$$f_r = -P_{\sum_{i \in M_1} b_{1ri} (S_i \operatorname{sgn} q_i |q_i|^{X_i} + h_i^{(r)}) - r} \quad (28)$$

$$-\sum_{i \in L_1} b_{1ri} P_i + \sum_{i \in N_1} b_{1ri} P_i = 0 \quad (r \in L_2) \quad (29)$$

$$q_i = \sum_{r \in E_2} b_{1ri} q_i \quad (i \in E_1) \quad (30)$$

Now let us move on to the mathematical formulation of the problem of optimising the operating mode of pumping stations when they work together on the water network:

$$y = \sum_{j \in N} (P_j^{(H)} - P_j^{(H)+}) \rightarrow \min_{\Omega} \quad (31)$$

$$q_i = \sum_{r \in M_2 \cup L_2 \cup N(\sigma)} b_{1ri} q_i + Q_i^+ \quad (i \in E_1). \quad (32)$$

$$Q_i^+ = \sum_{r \in N} b_{1ri} q_i^+ = \operatorname{const} \quad (i \in E_1). \quad (33)$$

$$q_j = q_j^+ \quad (j \in N) \quad (34)$$

$$P_j^{(H)} \geq P_j^{(H)+} \quad (j \in N) \quad (35)$$

The value of S_j is determined here by one of the well-known formulas or empirically, as the result of measurements and solutions to the parametric identification problem. Mathematically, this is a nonlinear programming problem with constraints in the form of equalities and one-way constraints of variables. The authors will solve it as follows: firstly, this problem will be solved, provided that the costs at pumping stations are known; then, based on this programme, the cost grid for the $(l-1)$ pumping station can be searched, where l is the number of these stations.

The initial data to optimise the mode of operation of the designed pumping stations when they work together in the network are: the structure of the network; the location of the inputs and outputs of the network, as well as the supply and flow of water in them; the parameters of the main sections: the length of the pipeline, the diameter of the pipeline, geodetic marks of the beginning and end of the pipeline section; the relationship between the pressure losses and the flow rate of the corresponding section of the water network; the minimum allowable free heads on fictitious sections (network outputs).

The purpose of the calculation is to determine the pressure at the inputs of the network and the water distribution in it that provides the specified water flow rates at the inputs and outputs of this network. Obviously, this problem has many solutions. For an unambiguous solution (the most economical one), it is necessary to determine the so-called dictating point of the network, at which the free head obtained as a result of the solution should be equal to the minimum allowable one.

Let us formulate this problem mathematically:

$$t = \sum_{j \in L} h_j^{(a)} q_j \rightarrow \min_{\Omega} \quad (36)$$

$$f_r = S_r \operatorname{sgn} q_r |q_r|^{x_r} + \sum_{i \in M_1} b_{1ri} S_i \operatorname{sgn} q_i |q_i|^{x_i} = 0 \quad (r \in M_2) \quad (37)$$

$$f_r = S_r \operatorname{sgn} q_r |q_r|^{x_i} - h_r^{(a)} + h_r^{(r)} + h_1^{(a)} + \sum_{i \in M_1} b_{1ri} (S_i \operatorname{sgn} q_i |q_i|^{x_i} + h_i^{(r)}) = 0 \quad (38)$$

$$q_i = \sum_{r \in M_2} b_{1ri} q_i + Q_i \quad (i \in E_1) \quad (39)$$

$$Q_i = \sum_{r \in L_2 \cup N \cup N^{(\sigma)}} b_{1r1} q_i^+ = \operatorname{const} \quad (i \in E_1) \quad (40)$$

$$h_j^{(H)} \geq h_j^{(H)+} \quad (j = N) \quad (41)$$

Here, the equations of the mathematical model are formulated with the following network encoding: the graph tree is selected in such a way that fictitious sections of the network, sections with active sources become chords. In this case, the real sections will partially become chords, and partially – tree branches. Branches of a tree with a pump are assigned the number 1; L, M , and N are indicated by many indexes of sections: those with active sources, main ones (water network sections), and fictitious ones, respectively. At the same time $L=L_1 \cup L_2$, $M=M_1 \cup M_2$, $N=N_2$, $L=\{1\}$, (1 and 2 are the indexes of tree branches and chords, respectively), and for any closed loop B , contains the backbone sections of the network:

$$h_r^{(r)} + \sum_{i \in M_1} b_{1ri} h_i^{(r)} = 0 \quad (r \in M_2) \quad (42)$$

where $q_j = q_j^+ = \operatorname{const} \quad (j \in L \cup N)$, $h_j^{(r)} \quad (j \in M)$ – the

difference of geodetic marks between the end and beginning (j) of the main section. In the above mathematical model, it is assumed that sections with active sources are directed from a fictitious node to the network, and fictitious sections are directed vice versa.

The purpose of the analysis is to construct the transfer function of the control object, consider the impact of the pipeline on the water supply process, and analyse the possibilities of switching from a distributed pipeline model to a concentrated one to reduce the order of the transfer function of the water supply system. To study the dynamics of processes, the authors will consider the transfer function of the water supply system as an object of control. The facility includes a pumping unit and pipelines. The pump unit consists of a pump and an electric motor.

A block diagram of the water supply management system is shown in Figure 6.

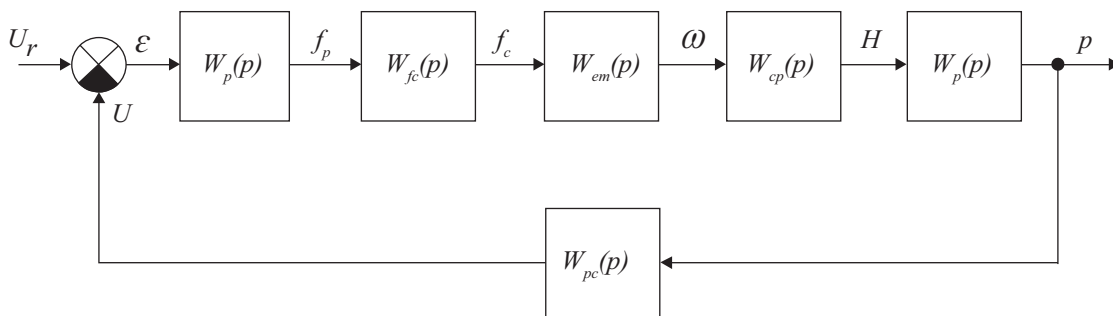


Figure 6. Block diagram of the water supply management system

The transfer function of a frequency converter is defined as:

$$W_{fc}(p) = \frac{f_c(p)}{f_p(p)} = \frac{k_{fc}}{(T_{fc}p + 1)} \quad (43)$$

where T_{fc} – time of the frequency converter; k_{fc} – frequency converter gain coefficient. The transfer function of an asynchronous electric motor will have the form:

$$W_{em}(p) = \frac{\omega(p)}{f(p)} = \frac{k_{em}}{(T_{em}p + 1)} \quad (44)$$

where T_{em} – electromechanical time of the electric motor; k_{em} – gain of the electric motor coefficient. The electromechanical time constant will be determined by the formula:

$$T_{em} = \frac{J\omega_0}{M_n} \quad (45)$$

where ω_0 – angular velocity of the rotor at the rated power supply frequency; M_n – starting torque of the motor. The transfer function of the centrifugal pump will have the form:

$$W_p = \frac{H(p)}{\omega(p)} = \frac{k_p}{(T_p p + 1)} \quad (46)$$

where H is the head of the centrifugal pump; T_p is the pump time constant; the pump time constant will be defined as:

$$T_p = \frac{4(d_2 - d_1)}{(\Omega z_p \ln(\frac{d_2}{d_1}))} \quad (47)$$

where d_1 is the input diameter of the circular grid of the pump; d_2 is the output diameter of the circular grid of the pump; Ω is the relative velocity of fluid movement in the interscapular space; z_p is the number of blades of the circular grid; k_p is the pump gain. The transfer function of a strain gauge pressure transmitter is described by the gain coefficient:

$$W_{pc}(p) = \frac{U(p)}{P(p)} = k_{pc} \quad (48)$$

where k_{pc} is the gain of the pressure converter; U is the output voltage of the converter proportional to the pressure signal. The water supply system is a distributed system: the pressure in pipelines does not spread instantly and changes not only in time but also in space. Processes in a water supply system with pipelines are described by partial differential equations. A system of equations can be written:

$$-\frac{\partial p}{\partial x} = \rho \left[\frac{\partial u}{\partial t} + F(u, x) \right] \quad (49)$$

$$-\frac{\partial p}{\partial t} = \rho c^2 \frac{\partial u}{\partial x} \quad (50)$$

where p is the average cross-sectional pressure; u is the fluid flow rate; t is the time; x is the coordinate along the pipeline length; ρ is the density of the liquid; c is the speed of sound in the liquid, considering the elasticity of the pipeline walls; $F(u, x)$ is a nonlinear function of viscous friction.

The speed of sound in a liquid is defined as:

$$c = \sqrt{\frac{E_1}{\rho} \left(1 + \frac{d}{\delta} \cdot \frac{E_1}{E_2} \right)^{-1}} \quad (51)$$

where E_1 is the volume modulus of elasticity of the liquid; E_2 is the modulus of elasticity of the pipe material; d is the inner diameter of the pipeline; δ is the wall thickness of the pipeline.

$$F(u, x) = \frac{\lambda}{2d} \cdot |u| \cdot u \quad (52)$$

where λ is the coefficient of hydraulic resistance, which depends on the Reynolds' number. The Reynolds' number can be determined by the formula:

$$\lambda = \frac{ud}{v} \quad (53)$$

where v is the kinematic viscosity of the liquid. To simplify the analysis and synthesis of control systems, it is proposed to replace the distributed part of equation (1.53), (1.54), namely the pipeline with a net delay link, provided that the pipeline is trunking and does not have significant branches that considerably affect its dynamic properties.

$$G_h = \frac{H(s, l)}{H_0(s)} = e^{-\frac{1}{v}s} \quad (54)$$

$$G_Q = \frac{Q(s, l)}{H_0(s)} = \sqrt{\frac{(gS/c^2)_j}{(1/gS)_j}} \cdot e^{-\frac{1}{v}s} \quad (55)$$

where G_h is the head transfer function of the pipeline; G_Q is the feed transfer function of the pipeline; v is the signal distribution speed.

It is known that:

$$v = \frac{1}{\sqrt{(1/gS)_j \cdot (gS/c^2)_j}} \quad (56)$$

where j is the j fragment of the pipeline; S is the cross-sectional area of the pipeline; d is the diameter of the pipeline; l is the length of the pipeline piece; λ is the dimensionless coefficient of resistance of the pipeline.

If the control point is set at some distance along the pipeline, in addition to the signal delay, some pressure drop will also be present, which depends on the resistance of the pipeline and the speed of fluid movement. Based on this, the pipeline gain is determined using the equation:

$$k_p = \frac{vS}{p} \quad (57)$$

where k_p is the gain coefficient of the pipeline; v is the speed of fluid movement in the pipeline;

$$v = \frac{Q}{S} \quad (58)$$

where p is the pressure at the end of the pipeline; S is the cross-sectional area of the pipeline. Now the pipeline transfer function can be represented as follows:

$$W_p(p) = \frac{P(p)}{H(p)} = k_p e^{-p\tau} \quad (59)$$

Since there is a clean delay in a water supply system with a long pipeline, it is necessary to ensure the stability of the control system. Considering that the length of the pipeline does not exceed a critical value and the system is stable, observable, and controlled, then the transfer function of the pipeline can be described using a first-order aperiodic link:

$$W_p(p) = \frac{P(p)}{H(p)} = \frac{k_p}{(T_p p + 1)} \quad (60)$$

Since an open control system is used in further studies, the transfer function of an open water supply control system acquires the following form:

$$W(p) = \frac{k_{fc}k_{em}k_p k_p k_{pc}}{(T_{fc}p + 1)(T_{em}p + 1)(T_p p + 1)(T_p p + 1)} \quad (61)$$

The transfer function of the object (1.65) has the fourth order, which complicates the study and construction of control systems, so it is proposed to replace the transfer function of the frequency converter with a gain factor, given that the vector method of controlling an asynchronous motor is used. Then the control object takes its final form:

$$W(p) = \frac{k_{fc}k_{em}k_p k_p k_{pc}}{(T_{em}p + 1)(T_p p + 1)(T_p p + 1)} \quad (62)$$

The transfer function of the water supply facility (1.66) has the third order and can be used in further research.

Let us consider a single-circuit closed water supply system. To make a model, a pump unit was selected that

has the following parameters: $T_m=0.026$ – electromechanical time constant of an asynchronous electric motor with a short-circuited rotor; $T_p=0.231$ – pump time constant; $T_{tc}=0.01$ – pump time constant; $k_m=5.061$ – motor gain factor; $k_p=5.22$ – pump gain factor; $k_{tc}=0.99$ – pump gain factor; $T3=T_m T_p T_{tc}=0.00006006$; $T2=T_m T_p + T_m T_{tc} + T_p T_{tc}=0.00231$; $k1 = k_m k_p k_{tc} = 26.15423$.

Existing water supply system regulators use only continuous functions in the control signal. The use of continuous functions in the control signal does not allow switching the water supply system to a given state in the shortest possible time. To ensure maximum performance, the proportional control law must be used. However, given the fact that the control influence in a real water supply system cannot be large, according to the engineering requirements, a restriction is imposed on it for the adequacy of the model. A block diagram of the control system using the proportional law is shown in Figure 7.

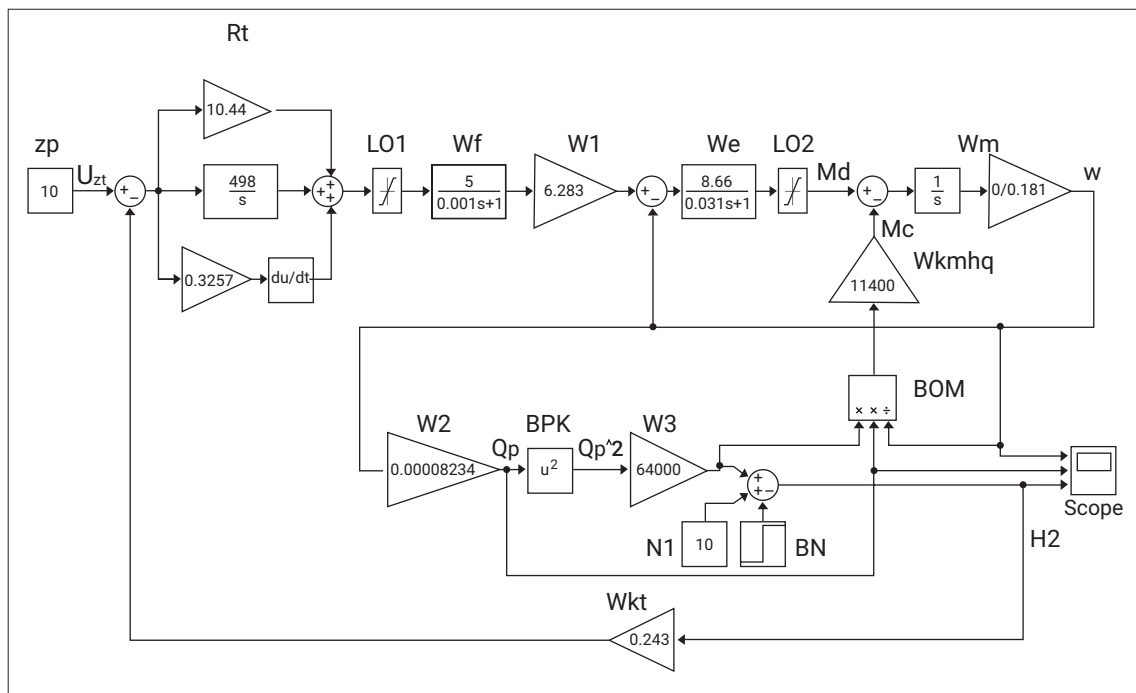


Figure 7. Computer model of a pumping station with pressure feedback

Modelling shows that existing regulators in water supply systems do not considerably improve the constant pressure in the pipeline when there is uneven water consumption. This is explained by the fact that the regulator slows down the transition process to prevent the system from becoming unstable but it does not consider fluctuations at the input. Operation of the water

supply system in transition mode and state stabilisation mode is possible using a regulator with a variable structure and parameters. The authors will conduct a study of such a regulator. A block diagram of such a regulator is shown in Figure 8.

The graph of transients in the water supply system using the regulator is shown in Figure 9.

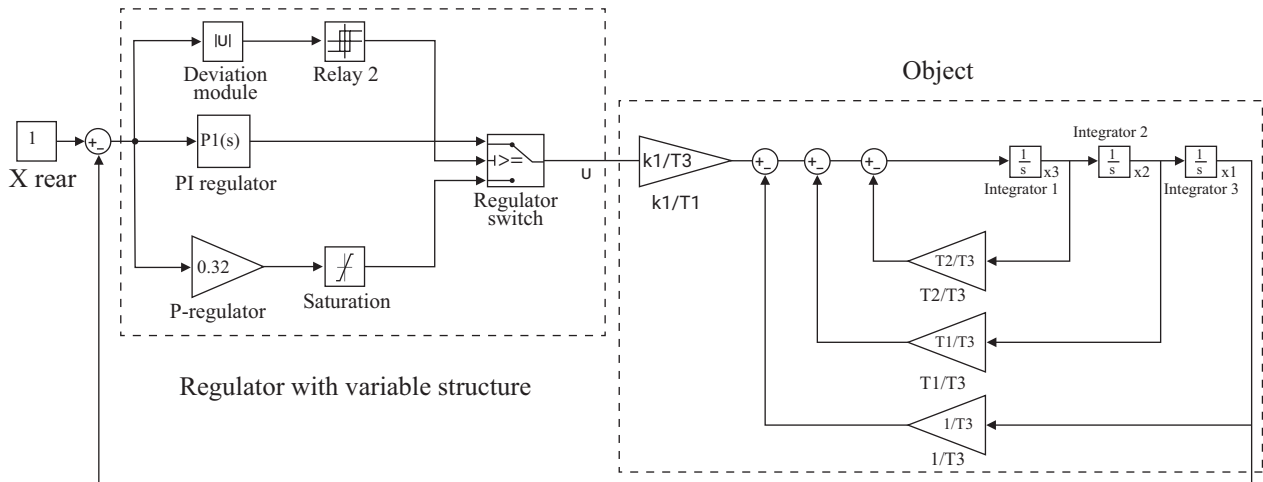


Figure 8. Computer model of a pumping station with pressure feedback

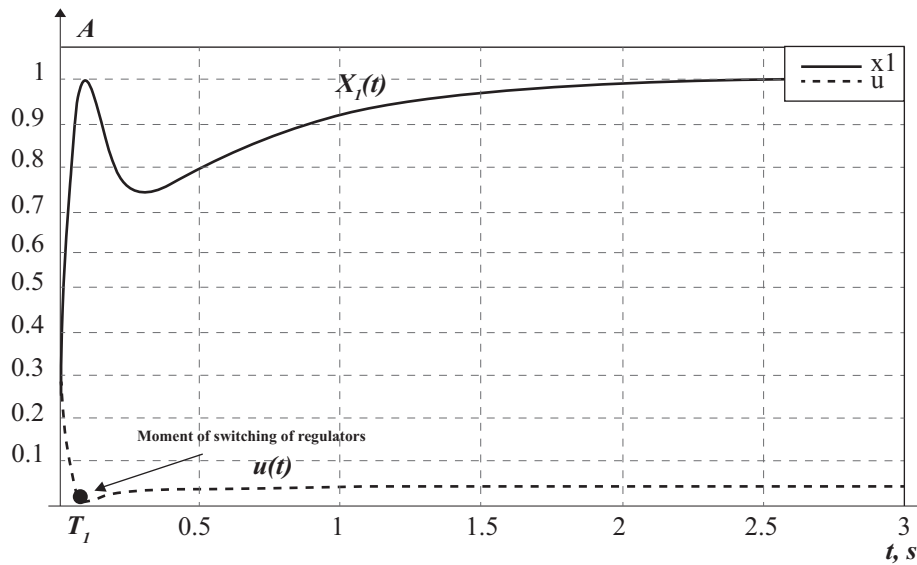


Figure 9. Schedule of operation of the water supply system using a variable structure regulator

Therefore, the use of regulators only using continuous functions in the control signal of the water supply system does not allow for a minimum transition time since an increase in the proportional coefficient will lead to unstable operation of the system. In a well-established mode, this regulator cannot minimise the efficiency functionality since it does not consider restrictions on derivatives and the amount of control influence.

The regulator, which has a variable structure and parameters, allows achieving the specified quality indicators in the transition mode and state stabilisation mode, but the consequence of its use is an increase in the duration of control of the water supply process.

Let us consider modelling and studying the regulator in the transition mode of the water supply system. A block diagram of the model is shown in Figure 10.

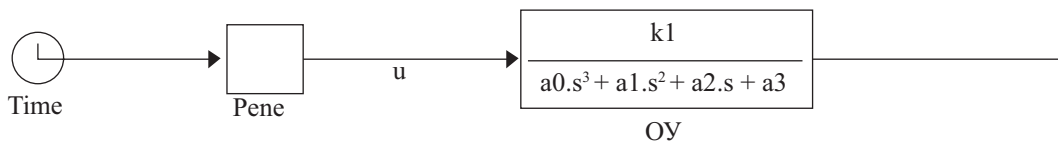


Figure 10. Block diagram of a water supply system model using a discontinuous function

The modelling results have shown that the transition process passes without fluctuations and overshoot. The transition time is 0.0311 seconds. Since two intervals and one switching are used for control, according to Feldbaum's theorem and Pontryagin's maximum principle, the trajectory of the system is optimal in terms of speed. During the modelling, only the transition mode was considered, so after the system went to the set value, the control was turned off and the movement of the system became free without external influence. The disadvantage of the control system that calculates the switching time is that it is necessary to have an accurate time counting device as part of the controller. The study and modelling of the water supply system at various gain parameters shows that the vector K also changes in proportion to the change in the system parameters, and the overall functionality is constant. That is, the value of the efficiency functional in this case does not depend on the gain of the transfer function. But changing the constant time also leads to a change in the values of the functionality.

Thus, the above control method provides a minimum of quality functionality in a well-established mode and shows the feasibility of using the device for analytical design of regulators in the water supply system.

CONCLUSIONS

In the paper, a study was conducted to assess the impact of the distribution and length of the pipeline network. The system of water supply and distribution is analysed, what criteria affect the correct performance of work and what problems may arise during operation for a long period of time are investigated. Based on the analysis, a mathematical model of the water supply system and a flow control model of the water supply system were developed. Since this paper examines the influence of the distribution and length of pipeline networks of the water supply system on the electric drive, the control of the water supply system was modeled based on existing regulators with a constant and variable structure. The results of modelling and experimental studies of the

water supply control system have shown:

1. The use of discontinuous functions in the control signal in transient mode allows getting the optimal speed trajectory of the water supply system. The conducted studies have shown that the use of discontinuous functions can reduce the duration of the transition mode by 3.8 times compared to existing regulators and, therewith, ensure minimal deviation and overshoot.

2. The proposed steady-state regulator improves the quality of control compared to existing regulators. According to the modelling results, the value of the quality functionality was reduced by 7.6 times.

3. It was shown that based on the proposed methods, it is possible to create a regulator with a variable structure and minimise the transition time, as well as minimise the quality functionality in a stable mode. It is proved that switching regulators should be carried out depending on the deviation of the initial pressure value and, thus, determine the operating mode of the water supply system.

Main scientific and practical results, their significance.

1. The approach to building automated control systems using regulators with variable structure has been further developed, which, unlike the known ones, takes into account the distributed nature of the control object in space, which allows applying the obtained control laws to water supply systems and thereby increasing the efficiency and reliability of their operation.

2. A computer model of the water supply system has been developed, which, unlike the known ones, takes into account the distribution in the space of the pipeline network, which will increase the efficiency of the design process of such systems.

The main scientific results of the paper were presented at the All-Ukrainian competition of student scientific papers in the area of "Electromechanics", which in 2021 was held remotely on the basis of the Dnipro State Technical University in Kamianske. As a result of the discussion, the paper "Improving the efficiency of distributed water supply systems by means of a regulated electric drive" received a diploma of the III degree.

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Підвищення ефективності роботи розподілених систем водопостачання засобами регульованого електропривода

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Анотація. Водопостачання насосної станції має задовольняти потреби споживача, які змінюються протягом доби, тому його продуктивність потребує коригування. Будь-яке відхилення продуктивності насосного агрегату від номіналу призводить до додаткових витрат на електроенергію. За таких умов велике значення у сфері водопостачання приділяється оптимізації роботи електроприводів насосної станції. Для регулювання продуктивності насосної станції часто вдаються до зміни кількості працюючих насосних агрегатів, двигуни яких запускаються безпосередньо від електричної мережі. На двигуни середньої та великої потужності діють технічні обмеження для прямого запуску, які доповнюються необхідністю підтримувати паузи між пусками, тому при забезпеченні необхідного значення продуктивності насосної станції дуже важливо враховувати особливості пуску насосних двигунів. Системи управління широко використовуються в області електроприводу та водопостачання, саме в цих сферах від ефективності роботи системи керування залежить кількість електроенергії, що буде споживатися технологічним процесом, або надійності його роботи. Відомо, що на насоси припадає приблизно половина всієї виробленої енергії, тому питання ефективних систем контролю є особливо актуальним у сфері водопостачання. Мета даної наукової роботи – підвищити надійність та ефективність роботи системи водопостачання за рахунок врахування під час керування електроприводами насосів, властивості розподіленості трубопровідної мережі, що дозволить узгодити роботу насосної станції, трубопровідної мережі та споживача. Для досягнення цієї мети було проведено дослідження оцінки впливу розподіленості та протяжності трубопровідної мережі. Також було проаналізовано систему подачі та розподілу води, досліджено які критерії впливають на коректне виконання роботи та які проблеми можуть виникати під час роботи в тривалій проміжок часу. Встановлено шляхи оптимізації роботи насосних станцій з метою підвищення економічності установок та їх енергоефективності. Розглянуто основні причини доцільності використання регульованого електроприводу для керування насосними агрегатами

Ключові слова: водопостачання, водопровід, приводи електронасосних станцій, математичні моделі електроприводу, насоси

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Rank Non-Parametric Correlation Analysis of Indicators of Heavy Metal Transition from Blood to Cow's Milk to Assess its Environmental Safety

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Abstract. Correlation analysis constitutes an essential method of statistical processing of the obtained scientific research results. Its proper application using special computer software and reliable results allow practically facilitating the work of the veterinary and livestock service in the production of environmentally safe high-quality cow's milk. The purpose of this study is to analyse the correlation between the content of toxic metals Cd and Pb in the blood and milk of cows using the STATISTICA computer software version 10.0. Scientific and economic experiments were conducted on dairy cows with different types of feeding. All animals selected according to the analogue method in terms of live weight and productivity were divided into three groups: the first control group and the second and third experimental groups. The diet included feeds with an excess of heavy metals, especially cadmium and lead. The high biological activity of pollutants affected their migration from the feed of the diet through the gastrointestinal tract to milk. To reduce intoxication of the animal body, premix "MP-A" was introduced into the main diet of cows of the second and third experimental groups, and in the third experimental group – premix "MP-2" and injection of the biological product "BP-9". First, using the Shapiro-Wilk's W test, the study verified the obtained data from laboratory tests of blood and milk for the concentration of toxic metals, the law of "normal" (Gaussian) distribution, and then the necessary Spearman's non-parametric rank correlation coefficient was selected for calculation. The analysis revealed a high correlation between the variables, which was within $r=0.82-0.91$ (Cd) and $r=0.78-0.96$ (Pb) with probability ($p<0.05$) in animals with different types of feeding. The discovered high correlation allows veterinary medicine specialists to quickly apply measures to reduce the toxic load of the body with elements only by analysing blood for cadmium and lead, and timely prevent the production of low-quality dairy raw materials, including using premix and phytobiopreparation tested in the experiment. Further research is aimed at analysing the correlation between other indicators of the quality and environmental safety of milk and feed, constructing regression equations that will practically contribute to the activities of specialists whose task is to ensure the production of high-quality environmentally safe cow's milk

Keywords: correlation, correlation coefficient, non-parametric correlation coefficient, Spearman correlation coefficient, dairy products, dairy cows, toxic metals



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INTRODUCTION

The danger of harmful effects of toxic heavy metals through food products, including water, milk, etc. On the human body is world-known due to the studies of J. Song et al. [1], W. Fischer et al. [2], C. Rezza et al. [3], E. Rahimi [4], Lili Liu et al. [5]. There are situations when pollutants enter the body of animals with feed containing an increased concentration of elements. Cd and Pb intake is associated with environmental risks to the body due to cumulative toxicity and negative effects on internal organs and systems, as proven by the studies of M. Canty et al. [6], S. Hashemi [7], S. Roggeman et al. [8]. Toxic metals, especially cadmium and lead, are freely absorbed in the gastrointestinal tract into the blood, and enter milk, which has been investigated in the studies of Y. Jolly et al. [9], D. Adriano [10], S. Ren-ju Tahir et al. [12]. It is challenging for veterinary and livestock specialists to assess the risks of dangerous effects of pollutants on animal health, quality, and environmental safety of milk produced, dairy raw materials that are used for processing and production of dairy products for human nutrition.

Conducting scientific and economic experiments to study the migration of toxic metals in the trophic chain and obtaining the corresponding array of digital data on numerous indicators of laboratory tests performed may not always indicate a high regularity of certain changes. Scientists have long and quite widely used various methods of correlation analysis of the obtained research results. At the same time, various computer software and analysis algorithms are used. It is essential not only to analyse the correlation strength between the indicators, but to choose the correct indicators as well. For example, scientists Lili Liu et al. [5] used a correlation study to identify the correlation between heavy metals in Hong Kong marine sediments over a long period of time from 1991 to 2011. Therewith, Spearman's, and then Pearson's rank correlations were used at the first stage. The bay and harbour (Victoria) were contaminated with heavy metals Pb and Cu, which correlated with Cr, Ni, and Zn contamination. Lili Liu et al. [5] believe that this is the first time they have used such an analysis to investigate environmental pollution, in addition to the fact that such methods have already been widely used in biology, sociology, and computer science. It is important that the investigated correlation analysis can be applied not only to marine sediments, but in other ecological systems as well, which is precisely what the authors of this study did. Other scientists Mingtao Xiang et al. [13] performed a correlation analysis of the heavy metals content in soil and plants grown to assess the risk of crop contamination and predict the danger of harmful effects of toxic metals, especially mercury and cadmium, on the human body. Scientists mostly paid attention to the contamination of soil and plants with heavy metals and did not pay attention to the correlation between them. The results indicated that the toxic metals studied in the soil had the greatest effect on zinc

levels in plants, while lead and chromium had a synergistic effect on zinc uptake by plants. Experiments prove the importance of correlation assessment for controlling the risk of contamination, which was not previously considered. The scientist Mariusz Rudy [14] from Poland investigated the correlation analysis of heavy metals' bioaccumulation in the tissues and organs (liver) of sheep, including muscle tissue, with age. Sheep were kept in eastern Poland. The experiment results demonstrated that with the age of sheep, the water content in muscle tissue decreases, the content of protein, fat, and ash increases. Contamination of meat and liver with cadmium and lead depends on the age of the animals. Between the youngest animals and the oldest, a difference of several times in the level of pollution was recorded. Examples of the use of correlation analysis can be given both in agriculture and in other areas related to environmental pollution in different countries, but the authors of this paper have investigated the correlation between the content of toxic metals in the blood of productive cows and milk for the first time.

Blood tests of cows on farms are regularly conducted by veterinary doctors, and analysis of the quality and environmental safety of milk is mainly conducted by livestock workers. The study of the correlation between the content of toxic metals in the blood and milk of animals is a convenient and fairly reliable indicator of predicting the safety of manufactured products (risk assessment) in the household. Therefore, *the purpose of this study* is to establish a correlation between the content of toxic metals Cd and Pb in the blood and milk of cows that consume feed with an increased concentration of environmentally hazardous toxicants for various types of feeding using the computer software for statistical data processing.

MATERIALS AND METHODS

In the farms located around the industrial city, during 2000-2007, scientific and economic experiments were conducted on dairy cows of Ukrainian black- and red- piebald dairy breeds. 126 heads of cows with silage-haylage-concentrate type of feeding, 63 – with silage-haylage, 36 – with silage and root crop, and 195 – with silage-hay type of feeding were selected for experiments, respectively. The experimental livestock was divided into three groups: the first control and the second and third experimental groups. Cows of all groups were fed feed containing heavy metals Cd, Pb, Cu, and Zn above the established maximum permissible concentrations. Animals of the second experimental group received an additional special antitoxic mineral and vitamin premix "MP-A", and the third – premix and subcutaneous injection of the biological product "BP-9". The average live weight of cows is 500-545 kg, the average daily milk yield is 14.0-14.8 kg. The duration of the comparison period was 42 days. Cows selected according to the method

of analogues in terms of live weight, productivity, were in the same conditions of feeding and keeping. The trial period lasted 120 days.

Biochemical analysis of samples of plant and animal origin, including blood and milk, for the content of macro-, microelements, toxic metals, etc. was performed according to Atomic Absorption Spectrophotometry method (AAS-30 spectrophotometer) [15]. Quality and environmental safety of milk was controlled pursuant to DSTU 3662-97 [16], as well as considering the requirements of international quality standards (Regulations (EC) No 853/2004 [17] and No 1881/2006 [18]). All manipulations with animals were conducted in accordance with the European Convention for the Protection of Vertebrates used for Experimental and Scientific Purposes (Strasbourg, 1986).

The data was analysed considering the features of the results obtained in the study: the sample size and type of data distribution, the nature of variances. For each sample, the average value of the feature in the sample (M) and the standard deviation (SD) are calculated, and the estimate is given as $M \pm SD$. Discrepancies between the average values were considered statistically

significant for $P < 0.05$. Correlation analysis – using the Spearman's non-parametric rank correlation coefficient, factoring in the Shapiro-Wilk's W test. The calculation was performed using the STATISTICA software package version 10.0 for the Windows 7 operating system.

RESULTS

Feeding dairy cows feed containing an increased content of toxic metals Cd and Pb affected their transition from the gastrointestinal tract to the blood, then to milk. To establish the strength of the correlation between the content of toxic metals in blood and milk, under the appropriate conditions of a scientific experiment, one of the non-parametric correlation coefficients was used – Spearman's rank correlation coefficient, since the Shapiro-Wilk's W test, which is considered the most powerful to establish the correspondence of the obtained data to the law of "normal" (Gaussian) distribution, especially in small samples ($n < 50$) of independent groups, indicated that the content of cadmium and lead in blood and milk cows with different types of feeding do not obey the law of normal distribution (Figs. 1-4).

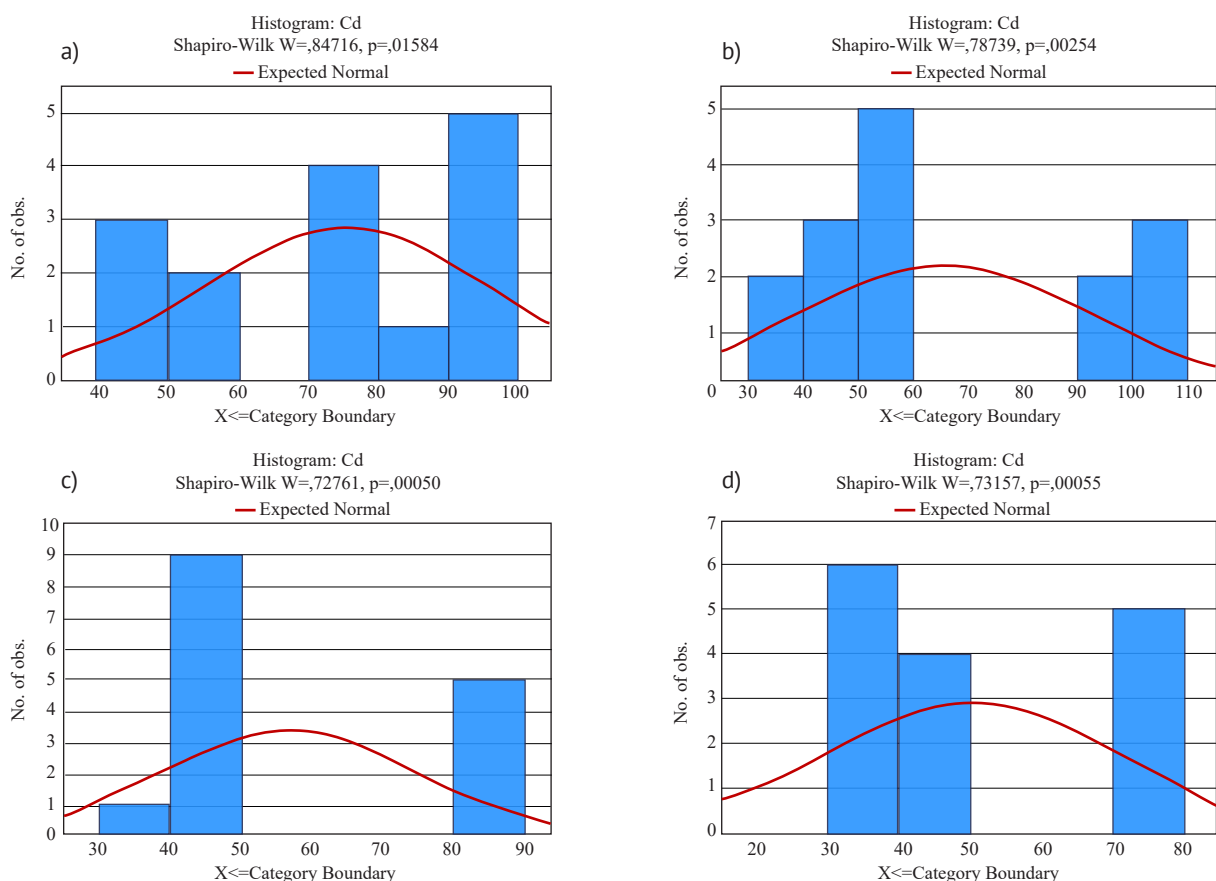


Figure 1. The result of analysing the distribution of the studied indicators of Cd content in the blood (nmol/l) of cows according to the Shapiro-Wilk's W test: a – silage-root crop type of feeding; b – silage-hay; c – silage-haylage; d – silage-haylage-concentrate

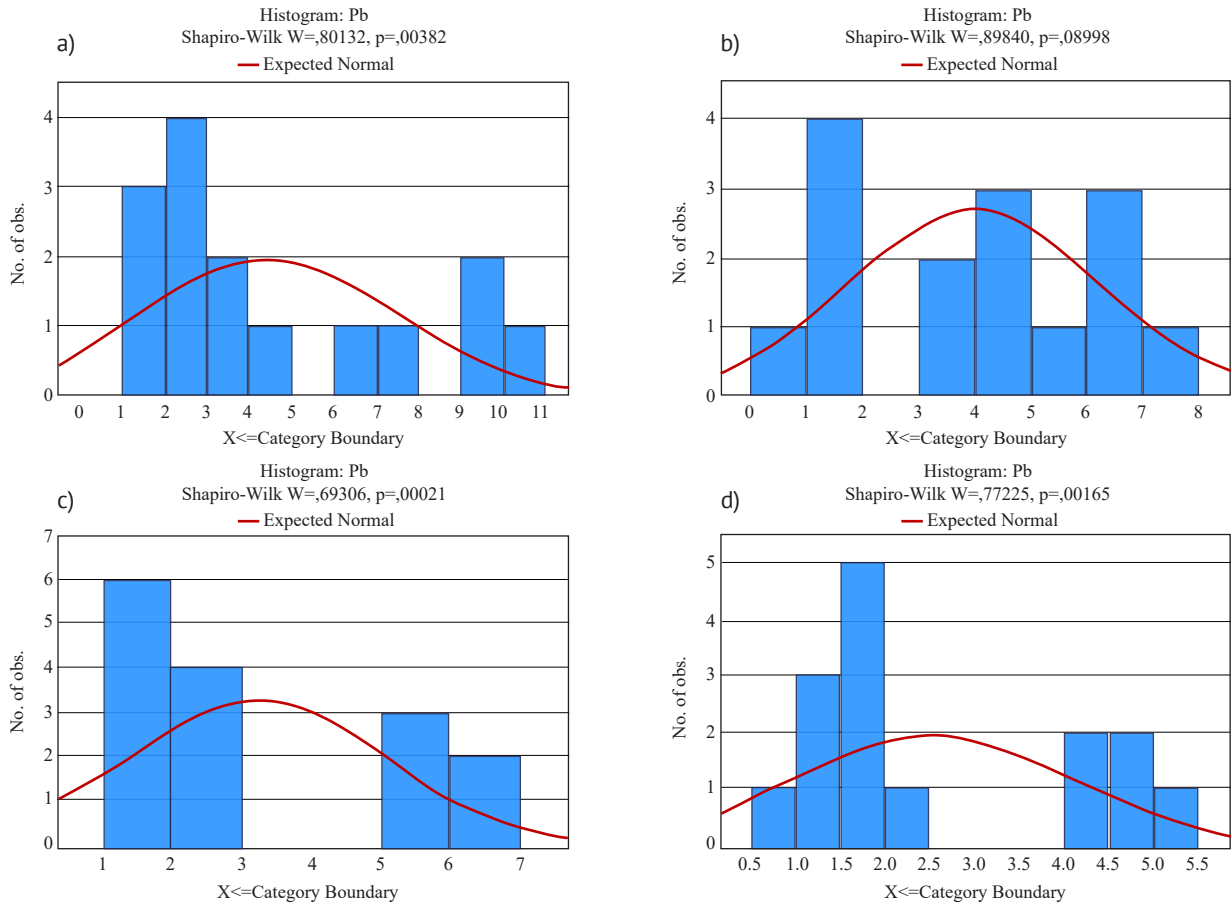


Figure 2. The result of analysing the distribution of the studied indicators of Pb content in the blood (nmol/l) of cows according to the Shapiro-Wilk's W test: a – silage-root crop type of feeding; b – silage-hay; c – silage-haylage; d – silage-haylage-concentrat

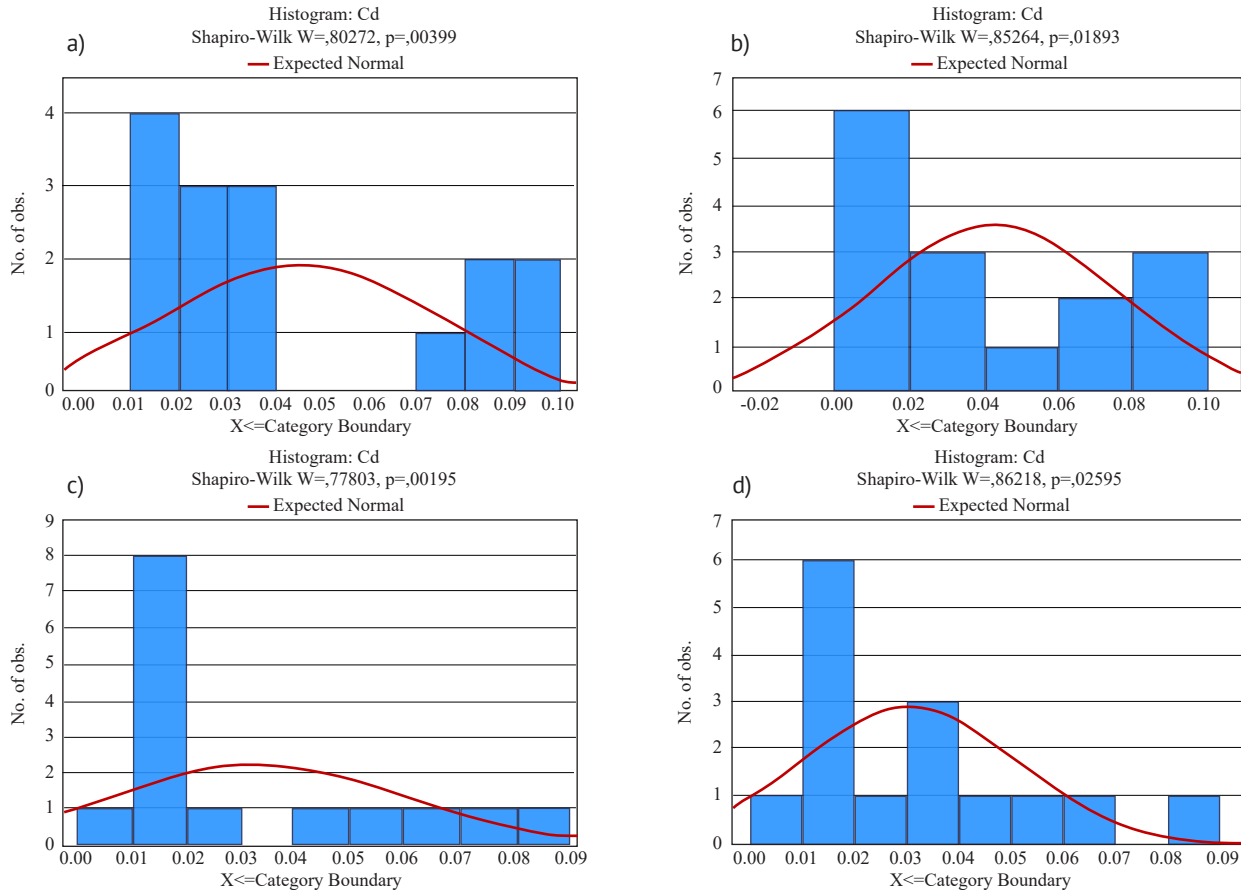


Figure 3. The result of analysing the distribution of the studied indicators of Cd content in the milk (mg/kg) of cows according to the Shapiro-Wilk's W test: a – silage-root crop type of feeding; b – silage-hay; c – silage-haylage; d – silage-haylage-concentrate

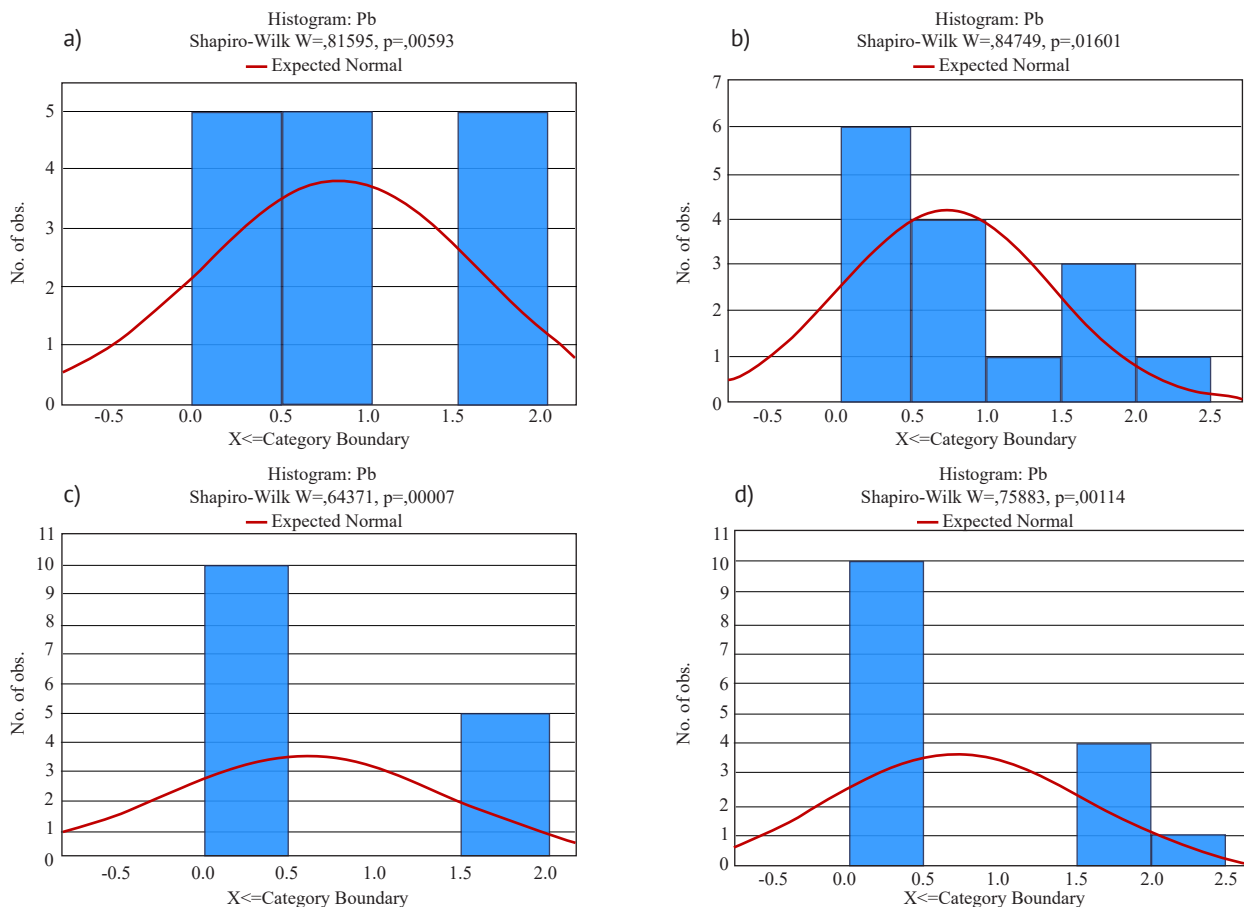


Figure 4. The result of analysing the distribution of the studied indicators of Pb content in the milk (mg/kg) of cows according to the Shapiro-Wilk's W test: a – silage-root crop type of feeding; b – silage-hay; c – silage-haylage; d – silage-haylage-concentrate

Application of the Pearson's coefficient in such situation entails conclusions that do not correspond to reality. It is more appropriate to apply the Pearson's correlation coefficient when the studied indicators correspond to the law of "normal" (Gaussian) distribution.

In the Statistics / Nonparametrics menu of the

STATISTICA software version 10.0, the Correlations module is launched (Spearman, Kendall tau, gamma). Next, in Variables, the columns containing the necessary data are selected and the Spearman R icon is clicked. A table with the analysis results will appear (Table 1 and Figs. 5-6).

Table 1. Toxic metals in cow's blood and milk at the end of the study period (M±SD)

Type of animal feeding	Mineral elements	Group of cows		
		1. Control	2. Experimental	3. Experimental
Silage and root crops	Blood			
	Cadmium, nmol/l	98.34±1.03	79.11±2.90	49.19±2.41
	Lead, nmol/l	8.32±1.65	3.02±0.99	1.98±0.16
	Milk			
	Cadmium, mg/kg	0.087±0.008	0.031±0.005	0.018±0.002
	Lead, mg/kg	1.835±0.093	0.614±0.085	0.014±0.003
Silage-hay	Blood			
	Cadmium, nmol/l	101.20±3.17	54.29±2.64	40.72±1.98
	Lead, nmol/l	6.54±0.45	4.01±0.64	1.38±0.28
	Milk			
	Cadmium, mg/kg	0.09±0.085	0.031±0.008	0.011±0.003
	Lead, mg/kg	1.641±0.253	0.515±0.064	0.027±0.012

Table 1, Continued

Type of animal feeding	Mineral elements	Group of cows		
		1. Control	2. Experimental	3. Experimental
Silage-haylage		Blood		
	Cadmium, nmol/l	81.17±0.60	48.19±0.73	41.61±1.05
	Lead, nmol/l	5.74±0.32	2.07±0.16	1.87±0.09
		Milk		
	Cadmium, mg/kg	0.068±0.017	0.017±0.004	0.012±0.002
	Lead, mg/kg	1.734±0.148	0.016±0.004	0.014±0.004
Silage-haylage-concentrate		Blood		
	Cadmium, nmol/l	77.94±0.99	40.64±0.54	32.14±0.55
	Lead, nmol/l	4.63±0.37	1.72±0.17	1.27±0.22
		Milk		
	Cadmium, mg/kg	0.053±0.019	0.024±0.009	0.014±0.004
	Lead, mg/kg	1.794±0.165	0.331±0.064	0.032±0.008

Note: the degree of probability compared to the data of the control group $P < 0.01$; $n = 5$

The correlation coefficient between the cadmium content in the blood and milk of cows for all types of feeding is positive and very high ($r = 0.82-0.91$), which indicates a direct and very high degree of correlation. The experiment established a lower correlation between the indicators in animals with silage-haylage-concentrate type of feeding $r = 0.82$ and silage-haylage – $r = 0.86$. The highest correlation coefficient was discovered in animals with silage-root feeding type ($r = 0.91$). The software highlights statistically significant correlation coefficients in red. Apart from calculating the correlation coefficient, the software allows simultaneously evaluating the statistical significance, which in all cases was $p < 0.05$. The correlation coefficient between the lead content in blood and milk ranged from 0.78 to 0.96. In cows with the silage-haylage type of feeding, the correlation was the weakest, but high ($r = 0.78$). The highest level is found in animals with silage-haylage-concentrate type ($r = 0.96$).

Thus, the use of Spearman's rank correlation coefficient, using the STATISTICA software version 10.0, made it possible to calculate and thereby reliably establish a high strength of correlation between the indicators essential for the experiment – the content of toxic metals Cd and Pb in the blood and milk of dairy cows with different types of feeding, which were received with a diet of feed with a high content of these dangerous elements.

DISCUSSION

Due to the complexity of ecological systems, the method of modelling using appropriate computer software is frequently employed to investigate them. Abstract models are more widely used in environmental research. In this case, the model refers to some abstract descriptions of

a particular object or phenomenon in the real world, which allows analysing its properties and making forecasts. The advantages of such models are that they enable the analysis of the state of ecological systems in relatively simple and inexpensive ways and predict the nature of their changes when certain changes are introduced to the ecosystem, for example, heavy metal pollution. The main requirement for abstract environmental models is accuracy and sufficient generality. In many cases, the accuracy of abstract models depends on the number of elements and system parameters selected for its construction. It should be borne in mind that inclusion of a multitude of components in the model complicates its analysis and creates “noise”. Conversely, too small a number of elements greatly distances the model from reality. Depending on the research apparatus, abstract models are as follows: verbal, graphic, mathematical, etc. For the purposes of this paper, it was decided to employ the construction of mathematical models based on the calculation of the correlation dependence between the indicators under study and the construction of the corresponding regression equations. In scientific research, it is often necessary to search for relationships between different indicators of the groups under study (precipitation and crop yield; body temperature and pulse rate, etc.). In this case, the content of mineral elements in blood and milk was analysed. Various types of correlation analysis are used to solve this type of problem. Correlation analysis allows assessing the direction of the correlation between two indicators (direct or inverse), as well as quantifying it using the correlation coefficient. The closer the correlation coefficient is to 1 (in modulus), the stronger the correlation between the indicators.

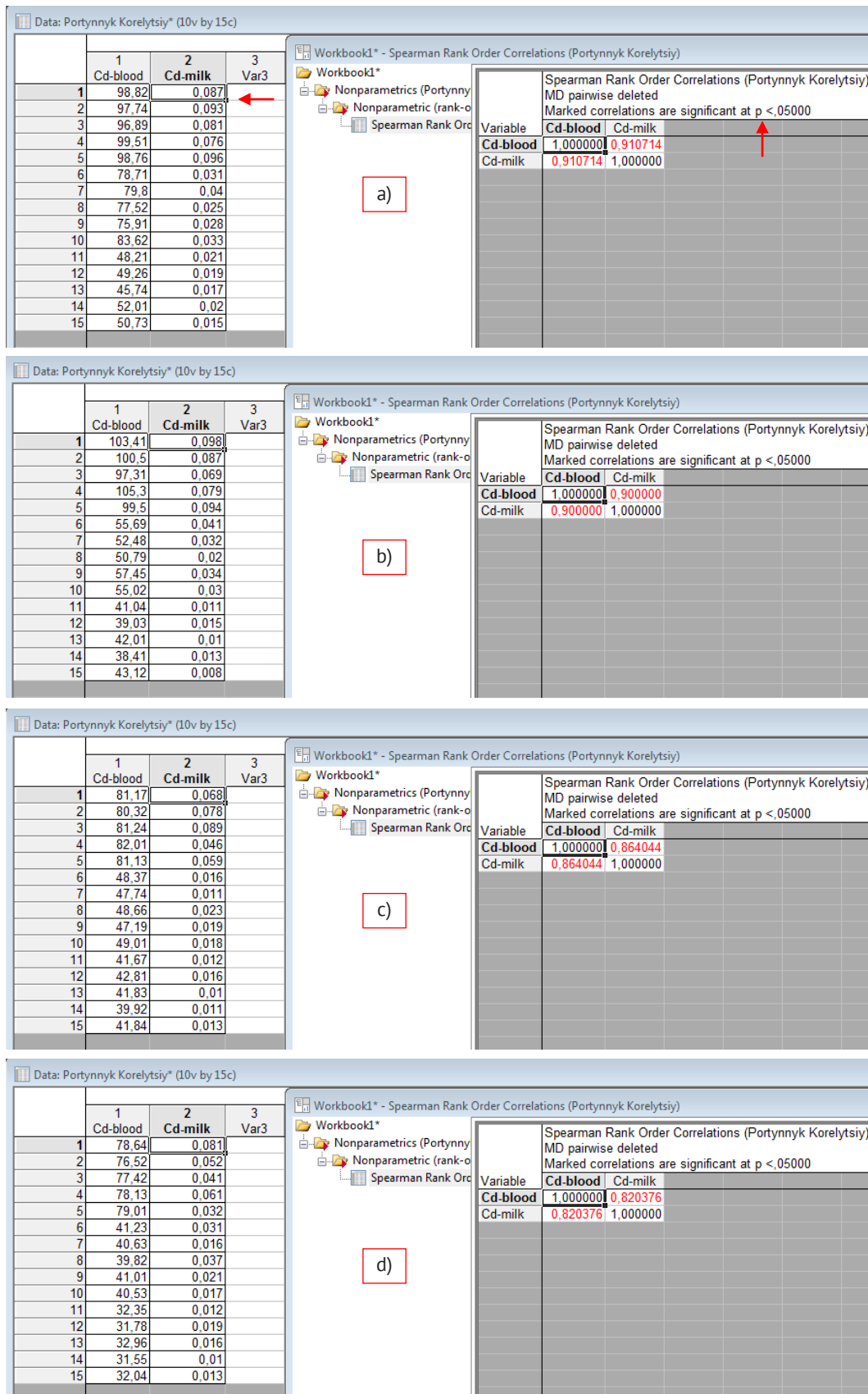


Figure 5. The indicators of cadmium content in the blood and milk of cows of groups 1, 2, 3 entered in the software window and the result – Spearman’s correlation coefficient between the content of the element in the blood and milk of animals: a – silage-root type of feeding; b – silage-hay; c – silage-haylage; d – silage-haylage-concentrate

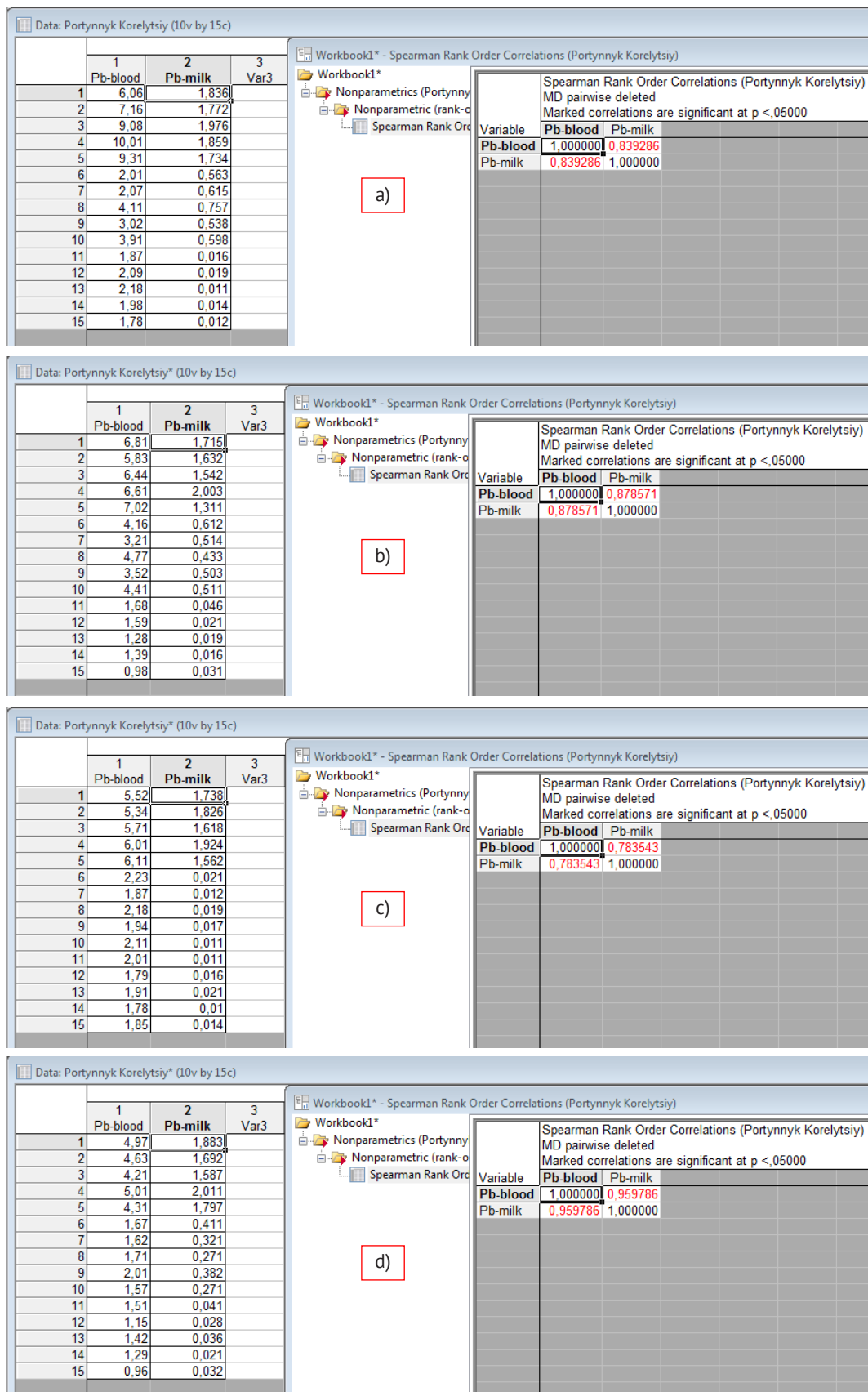


Figure 6. The indicators of lead content in the blood and milk of cows of groups 1, 2, 3 entered in the software window and the result – Spearman's correlation coefficient between the content of the element in the blood and milk of animals: a – silage-root type of feeding; b – silage-hay; c – silage-haylage; d – silage-haylage-concentrate

The correlation between the content of Cd and Pb in the blood and milk of cows is essential, which was investigated by the authors of this study in the experiment. The authors believe that regular medical examination of dairy cows by a veterinary doctor in agricultural enterprises located near industrial centres, ecosystems contaminated with toxic metals with simultaneous blood sampling for biochemical analysis and analysis of the Cd and Pb content will allow assessing the risks of the transition of pollutants to the dairy products – milk sold on the market as a product for human consumption, or dairy raw materials for the production. At the same time, it is difficult, sometimes even impractical, and generally unusual in the practice of a veterinary specialist to conduct a chemical analysis of blood and milk for heavy metals. For example, scientists S. Offor et al. [19] prove that the practice of analysing donated blood for people for the content of toxic metals is also unusual. Donor blood is tested for various pathogens, but not for the content of toxic metals. However, it is clearly established that a donor can accumulate these elements in the blood from various sources (professional activity, environment). Once in the human body, such blood can cause intoxication. The researchers emphasise that access to safe and adequate blood transfusions with minimal risk of exposure to toxic metals for recipients is also a public health issue. Scientists recommend reducing the risks of dangerous exposure to toxic metals – blood intended for transfusion, especially in vulnerable individuals, such as children, should be regularly examined for the concentration of toxicants. The main thing in the work of a veterinarian is prevention, to avert undesirable changes in the state of animal health, including to prevent deterioration of the quality and environmental safety of milk. The results of the correlation analysis made by the authors can substantially facilitate the production of high-quality milk. Timely detection of toxic metals in the blood will help specialists to take timely measures to exclude contaminated feed from the diet, if this is not possible – to balance the diet by timely introducing feed additives, or mineral-vitamin premixes of the type “MP-A”, as was done by the authors of this study in the experiment, mineral elements antagonists of cadmium and lead, to reduce their transition to milk, the introduction of proven drugs (protectors) of the type “BP-9” to reduce intoxication of the animals' bodies, improve their health, prevent poisoning. The high correlation between the content of toxicants in blood and milk established by the researchers at $r=0.82-0.91$ (Cd) and $r=0.78-0.96$ (Pb) ($P<0.05$), allows specialists to act effectively in production conditions.

Correlation analysis is widely and, most importantly, effectively used in the practice of scientists from different countries of the world, in various industries – not only in agriculture. Ying Han et al. [20] conducted a study of the effect of goat's milk enriched with oligosaccharides on the structures of the microbiota in the large

intestine of mice. Spearman's correlation analysis investigated the strength of the correlation between the microbiota and short-chain fatty acids in experimental animals. Spearman's correlation analysis demonstrated that propionic, isobutyric, and Valerian acids positively correlate with a particular microbiota. Accordingly, it is proved that goat's milk is useful for improving the microflora of the large intestine. Furthermore, Spearman's rank correlation coefficient was successfully applied in the analysis of indicators by scientists Han Young Joo et al. [21], who investigated the correlation between the dose of natural radiation and the incidence of human cancer in the Republic of Korea. Radiation dose rate data were taken from 171 observation points in 113 administrative districts of the country for 10 years from 2007 to 2016. The relative number of cancer cases for this analysis was the difference in the number of cancer patients per hundred thousand people per year in administrative districts with the five highest and five lowest natural gamma dose rates per year over the same period. An analysis of the correlation between two variables of Spearman's rank correlation coefficient was obtained using R. The result of the analysis indicated that Spearman's rank correlation coefficient exceeded 0.05, and the correlation between the two variables was not statistically significant.

Evidently, international scientific practice demonstrates that the Spearman's rank non-parametric correlation coefficient can establish both a high-strength correlation between the indicators under study, which is proved by Ying Han et al. [20], and vice versa, the low-strength correlation, as well as the low statistical probability, as proved by Han Young Joo et al. [21].

Computer software currently developed and available on the market, including STATISTICA version 10.0 for the Windows 7 operating system used by the authors of this study for correlation analysis proves its effectiveness. Given the preliminary verification of the obtained indicators of laboratory blood and milk analysis according to the Shapiro-Wilk's W test, it is advisable to use the Spearman's non-parametric rank correlation coefficient.

CONCLUSIONS

Using computer software of statistical data processing and the function of analysing the Spearman's non-parametric rank correlation, a high correlation was established between the transition of toxic metals cadmium and lead from blood to milk, which allows specialists to more confidently predict the environmental safety of produced milk (dairy raw materials) in case of dairy cattle breeding in conditions of increased anthropogenic load on agroecosystems and timely apply appropriate countermeasures to improve product quality.

The STATISTICA software version 10.0 used for statistical processing of biometric data, establishing the strength of correlation between the studied indicators,

and the reliability of research results is quite reliable, convenient for scientists and practitioners, and is as informative as possible. Correctly entered laboratory test data is quickly processed and simultaneously displayed both in the form of digital data and in the form of the necessary visual graphs.

Further research is aimed at conducting correlation and regression analysis using the same software, but with other indicators of environmental safety and quality of milk produced that are crucial in veterinary and livestock practice.

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Використання рангового непараметричного кореляційного аналізу показників переходу важких металів з крові в молоко корів для оцінки його екологічної безпеки

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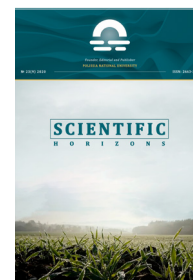
Анотація. Кореляційний аналіз є важливим методом статистичної обробки отриманих наукових результатів досліджень. Правильне його застосування з використанням спеціальних комп'ютерних програм і вірогідні результати дають змогу практично полегшити роботу ветеринарної і зоотехнічної служби під час виробництва екологічно безпечного високоякісного коров'ячого молока. Метою досліджень був кореляційний аналіз між вмістом токсичних металів Cd і Pb у крові та молоці корів за допомогою комп'ютерної програми STATISTICA версії 10.0. Науково-господарські дослідження проведено на дійних коровах з різними типами годівлі. Всіх тварин, відібраних методом аналогів за живою масою, продуктивністю, було поділено на три групи: першу контрольну та другу і третю дослідні групи. До складу раціону входили корми з надлишком важких металів, особливо, таких як кадмій і свинець. Висока біологічна активність полютантів вплинула на міграцію їх з кормів раціону через шлунково-кишковий тракт у молоко. Для зменшення інтоксикації організму тварин до основного раціону корів другої і третьої дослідних груп вводився премікс «МП-А», а в третій дослідній групі – премікс «МП-» та ін'єкція біопрепарату «БП-9». Спочатку за допомогою тесту Шапіро-Уїлка (Shapiro-Wilk's W test) було перевірено відповідність отриманих даних лабораторних аналізів крові та молока на концентрацію токсичних металів, закону «нормального» розподілу (Гауссова), а потім вибрано для розрахунку необхідний, у такому випадку, непараметричний ранговий коефіцієнт кореляції Спірмена. Аналіз встановив високу кореляційну залежність між змінними показниками, котра знаходилася в межах $r=0,82-0,91$ (Cd) та $r=0,78-0,96$ (Pb) з вірогідністю ($p<0,05$) у тварин з різними типами годівлі. Виявлений високий кореляційний зв'язок дасть змогу спеціалістам ветеринарної медицини лише за аналізом крові на вміст кадмію та свинцю швидко застосовувати заходи зі зниження токсичного навантаження організму елементами, вчасно попереджувати виробництво неякісної молочної сировини в т.ч. із застосуванням перевірених в експерименті преміксу та фітобіопрепарату. Подальші дослідження спрямовані на аналіз кореляційного зв'язку між іншими показниками якості та екологічної безпеки молока, кормів, побудову рівнянь регресії, котрі практично сприятимуть діяльності спеціалістів, завданням яких є забезпечення виробництва високоякісного екологічно безпечного коров'ячого молока

Ключові слова: кореляція, коефіцієнт кореляції, непараметричний коефіцієнт кореляції, коефіцієнт кореляції Спірмена, молочна сировина, дійні корови, токсичні метали

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Behavior and Energy Losses of Cows during the Period of Low Temperatures

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Abstract. Over the past 20 years, dairy farms in Ukraine have been actively introducing the keeping of cows in easy-to-assemble premises. However, in a moderate climate (with four distinct year seasons), the issues of microclimate, energy losses of animals and their behavior during the cold period of the year for keeping in such premises have not been fully studied. The purpose of this work was to study the influence of the heat insulation elements use of side curtains in easy-to-assemble premises during the period of low temperatures on microclimate, energy outgoings for thermoregulation and behavior of cows. The research conducted in the central part of Ukraine (Kyiv region). The research was conducted during January-February (29-43 days of the year) 2021. This period characterized by low average daily temperatures of -12.2 – -18.7°C, strong wind gusts and daily precipitation in the form of snow. Two easy-to-assemble premises for 400 heads were used for research. Parameters of placements (LxWxH): 150x32x10.5 m. The first one was without the use of curtains heat insulation elements, and the second one was with these elements of heat insulation. It was found that the use of polycarbonate wall heat insulation elements had a positive effect on the microclimate in the placement during the period of low temperatures. Indicators of average daily air temperatures in the placement were 3.2 and 8.8°C higher compared to the temperature in the same premise without the use of heat insulation elements and the environment. The wind speed also differed by 0.18 and 11.04 m/s, respectively. In addition, the heat insulation of the walls affected the temperature under the lying cow (+1.8°C), energy outgoings for thermoregulation (-1.93 MJ) and the number of cows that lay in the period of the lowest temperatures (+3.23-9.83%) compared to the placement without heat insulation elements. The difference in temperature of rubber carpet in the compared premises was significant: +3.3°C in the premises with heat insulation elements compared to the premises without heat insulation

Keywords: dairy, cold stress, easy-to-assemble premises, Wind-Cold index, Cold-Stress index



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INTRODUCTION

The efficiency of milk production largely depends on how to use animals properly, taking into account their biological characteristics, including behavior. Behavior is one of the most important indicators of detecting any abnormalities in animal health and productivity. It appears in all elements of production technology, forming in combination with climatic (weather, microclimate), planning (premises, stalls, playgrounds), technical (mechanisms and equipment) and organizational (daily routine) complex system "organism-environment" [1].

Ethological and physiological studies of the effects of weather phenomena occupy an important place in the development of effective methods in agricultural production. In the system of interaction "organism-environment" such environmental factors as climate and weather become important. Influencing agricultural production, they determine the efficiency of livestock and crop production. Ethological researches are necessary, first of all, for creation of optimal housing conditions, both at industrial complexes and at traditional farms. Dealing with the current intensity of dairy farming, weather and climatic conditions are an important component of the proper organization of cattle keeping and livestock farms' infrastructure and require some understanding of the mechanisms of meteorological conditions influence on animals and the ability to manage these mechanisms in practical animal husbandry. The study of behavioral reactions of animals of different breeds makes it possible to find ways to increase their productivity under specific conditions of feeding and keeping [2].

It is known that changes under external conditions lead to a restructuring of the adaptive behavior of animals, their motor activity. In a certain environment, the behavior of animals remains constant only when their daily routine is not limited and has no additional loads. The animal and the environment in which it lives form an integral unit. Each change in environmental conditions causes some disturbance in the vital balance of animals, forcing them to adapt to these changes. The ability of cows to resist these changes depends on species, breed, age and technological differences [3].

Adaptation of livestock breeds to local climatic conditions is an important feature of modern agriculture, as it helps to reduce the impact of temperature stress to which animals are exposed, and leads to increased livestock production. Under the influence of evolutionary factors, cattle underwent a long natural selection and adapted to various environmental conditions from Africa and equatorial America to central and northern Siberia. Domestication has resulted in more than 1.000 existing breeds with varying levels of productivity, product quality, feed conversion and other economically important characteristics [4].

Thermoregulatory mechanisms allow animals to adapt to different temperature fluctuations and tolerate

significant deviations in air temperature. However, at violation of the heat balance in cows, resistance and productivity are reduced and there are significant changes in behavioral responses compared to the normal state. Functional abnormalities in the body of domestic animals are possible due to too high and too low air temperatures. Prolonged exposure to high or low temperatures increases (or decreases) heart rate and respiration, activates sweat glands, evaporation, reduces mobility, appetite, feed conversion, feed nutrient intake, productivity and rest duration [5].

Warming of light-ventilation curtains in winter is of great importance when keeping cows in easily assembled premises in countries with a temperate-continental climate, including Ukraine. It has been established that the use of insulation of curtains with the use of polyvinyl chloride can prolong for 13 days the permissible norms of wind speed indoors and more effectively protect animals from the environment at different categories of wind speed, as well as reduce indoor air speed by 11.68-21.74% compared to uninsulated rooms of different configurations and heights of longitudinal walls [6].

The purpose of this work was to study the effect of heat insulation elements use of side curtains made of polycarbonate material in easy-to-assemble barn during the period of low temperatures on indicators of microclimate, resting place temperature, energy outgoings for thermoregulation and behavior of cows.

LITERATURE REVIEW

The influence of weather factors on the welfare and productivity of cows has been studied in the vast majority in terms of high temperatures [7]. The influence of cold on the body mostly been studied in beef cattle or dairy cattle under conditions of year-round grazing [8]. However, in recent decades, due to global climate change trends in Central and Eastern Europe there have been increasing winter temperature fluctuations that have had a negative impact on the welfare of dairy cows [9]. These processes cause great losses to agricultural producers due to reduced productivity and irrational use of feed resources [10].

The value of ambient temperature has a fundamental influence on the functioning of dairy cattle [11]. S. Angrecka found that thermo-neutral for the body of dairy cattle is the temperature in the range from -5 to 25°C [12]. J. West states that a change in temperature in the range from -0.5 to +25°C does not affect the productivity of cows [13]. Most breeds are quite sensitive to higher and lower temperatures in this range. A. Yáñez-Pizaña in his research indicates that dairy cattle and Water Buffalo are able to produce milk at temperatures up to -30°C under conditions of limiting the effects of wind and precipitation [14]. A. Yurchenko report that Yakut cattle found above the Arctic Circle and are able

to adapt to too low temperatures (up to -50°C) [4]. Under conditions of thermo-neutral temperature, the body spends minimum amount of energy to maintain life or balance with the environment. Nonetheless, the amount of heat lost is equal to the amount of produced heat. In the measure of moving away from the optimum temperature in the direction of its reduction, energy exchange and the level of heat production increases, which leads to irrational feed costs and a corresponding decrease in feed conversion [15-17]. Cold weather affects the physiological characteristics and behavior of cattle [1]. The sympathetic nervous system causes three main physiological responses to cold stress: increased heat production metabolism, increased heart rate, and mobilization of free fatty acids for metabolism [18]. Behavioral responses to low temperatures can be divided into two categories: the animal's search for a warm, comfortable place to rest to reduce the effect of temperature and change the duration of basic behaviors [19].

F. Duranovich report about the negative effects of prolonged cold load on cows' bodies. Studies in New Zealand under pasture conditions indicate significant changes in behavior and productivity during the low temperature period [20]. The duration of lying and grazing in cows decreased compared to the thermo-neutral period. One of the solutions to this issue, along with genetic

and feeding factors, are the factors of modernization of the premises, which would take into account the peculiarities of seasonal sharp changes in the main weather indicators [21]. Such factors include the installation of fans and irrigation systems, installation of canopies on feedlots in summer and heat insulation of premises in winter [12; 22].

MATERIALS AND METHODS

Climate and Barns

The research was conducted in the central part of Ukraine (Kyiv region $49^{\circ}51'27''$ North latitude, $30^{\circ}6'36''$ East longitude). Two easy-to-assemble barns with a loose housing of 400 cows were used for the research. Parameters of placements (LxWxH): $150 \times 32 \times 10.5$ m. The first one was without use of heat elements of curtains, and the second analogous one was with heat elements of longitudinal walls by polycarbonate glass (Fig. 1). One section of polycarbonate glass (Carboglass, Ukraine) has parameters: $5 \times 1.85 \times 0.01$ m. Sections of polycarbonate mounted to internal parties of vertical metal designs for the period of low temperatures (November-March) in the plane of lateral curtains. The transparency of polycarbonate glass is 86%. The material has high thermal heat insulation, sound heat insulation (17 dB) and impact resistance (900 kJ/m^2) properties.

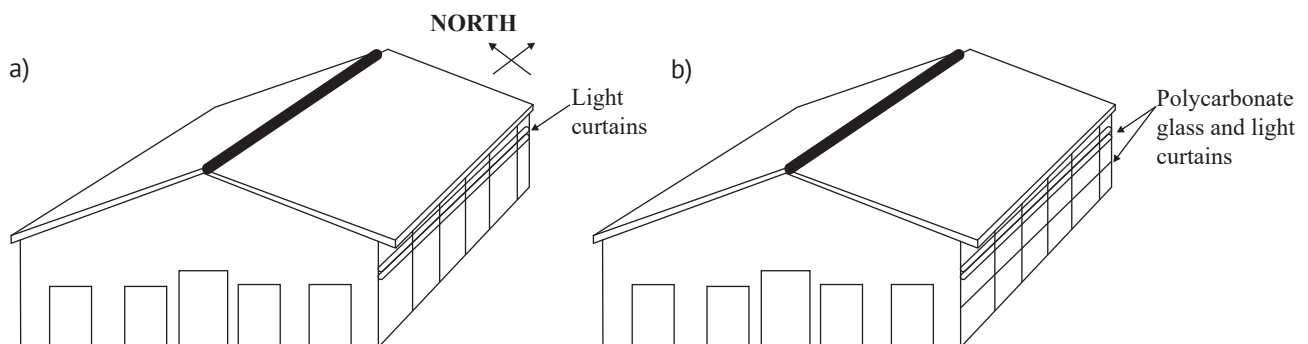


Figure 1. Easy-to-assemble premises without (a) and with (b) elements of heat insulation

The research was conducted during January-February (29-43 days of the year) 2021. This period characterized by low average daily temperatures of -12.2 – -18.7°C , strong wind gusts and daily precipitation in the form of snow. The duration of daylight during the experimental period ranged from 9 hours 11 minutes to 9 hours 57 minutes.

Measurement Methodology

The average daily air temperature, relative humidity, wind speed and precipitation were determined according to the Kyiv Center for Hydrometeorology. The temperature and relative humidity were measured by VOLT CRAFT DL-141 sensor (Germany) with a measuring range for temperatures from -40 to $+70^{\circ}\text{C}$ and relative humidity from 0 to 100%. The sensors were placed in the zone occupied by cows 0.5 m above the floor. All the measurement results

were recorded automatically every 10 min. The wind speed inside the barn was determined by wind speed and direction sensor TFA WeatherHub (TFA, China). The cows skin surface temperature was determined in two places: on rumen and in the region of the last inter costal space by using a remote infrared thermometer Thermo Spot-Plus (Germany). The temperature at the resting place as well as under the lying cow was determined by the thermometer A36PF-D43 (USA). Costs of energy for heat production were calculated according to the methods of C.T. Kadzere [23]. Cow behavior was determined by using indoor security cameras. 8 Hikvision cameras (Full HD) were installed in both barns. With an interval of 2 hours recorded the number of cows that lie, stand, consume feed and drink water. Recreation areas in both rooms were equipped with rubber carpets produced by Kraiburg (Germany). Daily application of cereal straw is 2.0 kg per 1 head.

Animals

Holstein cattle cows (93-118 days of lactation) used to study the main behavioral indicators. The location of the sections in which the cows were housed in both buildings was similar. In the room without the use of heat insulation elements, the number of groups was $n=88$, and in the room with heat insulation elements made of polycarbonate glass $n=85$.

Calculation of wind chill temperature index and cold stress index

The wind chill temperature index (WCT) was calculated according to C. Tucker [24]. This index helps to evaluate the effect of low air temperature in combination with the wind speed on the cold stress of animals:

$$WCT=13.12+0.6215 \cdot T_{air} \cdot 13.17 \cdot V^{0.16}+0.3965 \cdot T_{air} \cdot V^{0.16} \quad (1)$$

where: WCT – wind chill temperature, °C; T_{air} – air temperature, °C; V – wind speed, km h^{-1} .

The cold-stress index (CSI), which indicates the level of animals stress resistance to sharp wind speed and precipitation, was determined by the J.R. Donnelly method [25]:

$$CSI=[11.7+(3.1 \cdot WS \cdot 0.5)] \cdot (40-T)+481+R \quad (2)$$

where: CSI – cold-stress index, $\text{MJ/m}^2/\text{h}$; WS – mean daily wind speed, m s^{-1} ; T – is the mean daily temperature, °C.

$$R=418 \cdot (1-e^{-0.04 \cdot rain}) \quad (3)$$

where: $rain$ is the total daily rainfall in millimeters; e – natural logarithm = 2.718.

Statistical Analysis

The obtained data were statistically processed using STATISTICA (Version 11.0, 2012) software. The Student's t -test was used to estimate the statistical significance of the obtained values. Data were considered significant at $P<0.05$, $P<0.01$, $P<0.001$.

RESULTS AND DISCUSSION

The results of research showed the influence of the use of polycarbonate heat insulation elements on the average daily values of air temperature, relative humidity and wind speed in the premise (Table 1). These figures per 3.2°C; 0.2% and 0.18 m/s were dominated the similar results obtained in the placement without the use of heat insulation elements. Comparing the indicators of the microclimate in the rooms with environmental weather conditions, the largest difference found in terms of wind speed. In the rooms without the use of heat insulation elements, the difference was – 10.86 m/s, while in the premises with the use of heat insulation elements – 11.04 m/s compared to the average environmental temperature. Indicators of air temperature in the studied premises were respectively higher by: 5.6 and 8.8°C compared to ambient temperature. Regarding the relative humidity, the difference with the environmental indicator constituted 8.4% in the rooms without heat insulation elements, and in the insulated premise 8.6%.

Table 1. Indicators of air temperature, relative humidity and wind speed of the environment and premises

Indicators	Environment			Easy-to-assemble premises			Easy-to-assemble premises with elements of heat insulation		
	Mean±	Min	Max	Mean±	Min	Max	Mean±	Min	Max
	SEM			SEM			SEM		
Temperature, °C	-15.9±0.17	-12.2	-18.7	-10.3±0.08 ^{†††}	-5.9	-12.7	-7.1±0.06 ^{†††;***}	-4.8	-9.8
Relative humidity, %	94.3±5.56	88.1	98.0	85.9±2.19	77.6	90.8	85.7±2.74	79.5	92.7
Speed of wind movement, m/sec	11.6±0.27	7.3	15.8	0.74±0.05 ^{†††}	0.62	0.85	0.56±0.03 ^{†††;***}	0.48	0.64

Note: SEM: standard error of mean; ^{†††} $P<0.001$ as compared with environment; ^{**} $P<0.01$; ^{***} $P<0.001$ as compared with easy-to-assemble premises

The results of research coincide with the data obtained in the studies of S. Angrecka conducted in Poland, which showed a significant temperature decrease in the premise of the easy-to-assemble type during prolonged negative temperatures during winter [26]. F.K. Teye in their studies conducted in Estonia and Finland indicate a decrease in daily air temperature in barns to -20°C and below during periods when the ambient temperature was below -30°C [27]. A group of researchers obtained similar research results from China Z. Cao, who indicate

a decrease in air temperature in easy-to-assemble premise (from -0.97 to 8.10°C) during the period when the ambient temperature was -20°C and below [28].

Among the weather factors that affect the comfort and well-being of cows during the year is wind speed. In winter, at negative temperatures, gusts of wind can lower the temperature of air masses, which in turn affects the productivity, energy outgoings for thermoregulation and animal behavior. Research coincides with data obtained by P. Herbut, which indicates an increase in wind

speed in rooms with side curtains during periods of low temperatures [29].

The greatest influence on the duration of animals rest, along with the nature of the kennel (hard or elastic coating, the presence or absence of litter, clean or dirty, dry or wet) and the type of litter, the heat capacity of litter material has. When the animal is lying down, $\frac{1}{3}$ part of the surface of its body is in contact with the floor, so the kennel should be warm enough. Heat losses through the floor are 12-20% of the total heat losses of the room and depend on the thermo-physical characteristics of the floor and bedding material. The temperature indicators of rubber carpets did not differ from the average daily temperature in the premises (Table 2). Thus, in the premises

without heat insulation elements the difference was $+0.1^{\circ}\text{C}$, and in the premises with heat insulation elements: $+0.2^{\circ}\text{C}$. The temperature difference of the carpets between the actual premises was significant: $+3.3^{\circ}\text{C}$ in the premises with heat insulation elements compared to a room without heat insulation. Body and skin temperature of dairy cows vary depending on weather conditions, microclimate parameters, as well as options for keeping animals and the type of litter material. In research, the influence of heat insulation elements on the skin temperature during low temperatures has been established. In the room with the use of heat insulation elements, the value of this indicator was 0.4°C higher compared to the control premise.

Table 2. Indicators of temperature of places of rest, skin of animals and energy outgoings for heat production

Indicators	Easy-to-assemble premises			Easy-to-assemble premises with elements of heat insulation		
	Mean \pm SEM	Min	Max	Mean \pm SEM	Min	Max
Temperature of rubber carpet, $^{\circ}\text{C}$	-10.2 \pm 0.08	-5.6	-12.3	-6.9 \pm 0.06***	-4.4	-9.5
Temperature of animal's skin, $^{\circ}\text{C}$	28.8 \pm 0.11	28.2	29.3	30.2 \pm 0.14***	29.5	30.8
Temperature under the lying cow, $^{\circ}\text{C}$	20.3 \pm 0.09	18.9	21.6	22.1 \pm 0.12***	21.6	22.8
Energy for heat production, MJ	54.37 \pm 0.79	54.71	54.03	52.44 \pm 0.53'	52.61	52.32
Wind-Cold index, $^{\circ}\text{C}$	-13.41 \pm 0.34	-16.11	-10.02	-9.14 \pm 0.21***	11.39	6.85
Cold-Stress index, MJ/m ² /h	1517.14 \pm 25.41	1502.56	1535.08	1454.83 \pm 12.98'	1436.77	1471.54

Note: ' $P < 0.05$; *** $P < 0.001$ as compared with easy-to-assemble premises

Heat losses through the floor are 12-20% of the total heat losses of the room and depend on the thermo-physical characteristics of the floor and bedding material. It is quite irrational for an animal to lose the energy of fodder for the creation and use of thermal energy, for heating the kennel, instead of converting it into milk. At low temperatures, cows increase the outgoings of physiological heat. When these outgoings exceed 100 kcal/h (0.418 MJ/h), then during 12 hours (average duration of rest of the cow in the supine position) they are equivalent per caloric content of 2 kg of milk. The value of the temperature under the lying cow in the cold period quantitatively demonstrates the energy outgoings intended for thermoregulatory processes for heating the rest area. The difference between the premises with heat insulation and without it constituted $+1.8^{\circ}\text{C}$.

Prolonged low average daily temperature causes an increase of energy outgoings for heat production. Energy outgoings for evaporation, radiation and convection directly related to ambient temperature and have

a significant impact on the behavior and productivity of cows. It was found that in the room with heat insulation elements; the average daily outgoings of exchange energy for heat production was 1.93 MJ lower than in the room without heat insulation.

Indicators of wind-cold (WCT) and cold-stress (CSI) indices assessed the effects of low temperatures in combination with air velocity and precipitation on cold stress. The value of WCT evaluates the effect of low temperatures combined with the speed of indoor air movement on productivity, comfort and housing behavior of cows. It was found that in the premise with heat insulation elements, the average WCT value was 4.27°C higher than in the premises without heat insulation elements. Knowledge of CSI allows you to consider how wind speed and quantity of weather elements, which are the main factors in the perception of objective temperature, influence on the productivity and behavior of cows. In premise with heat insulation elements, the CSI value was 80.37 MJ/m²/h lower than in the premise without the

use of heat insulation elements. The dependence of indoor air temperature and basic behavior indicators has been established (Table 3). Thus, during the period of maximum low-temperature load from 00.00 to 06.00, the vast majority of animals in both rooms rested lying down. In the premise without heat insulation elements (temperature range from -11.7 to -12.4°C), the number of cows that rested during this period ranged from 56.81% to 78.40%. Whereas in the premise with heat

insulation elements (temperature range from -8.5 to -9.8°C), this value constituted from 60.04% to 88.23%. It is believed that for maximum milk production in two hours after the distribution of feed cows should rest in lying position. In studies, the number of cows resting in lying position at 10.00 am and 20.00 pm in the premise with heat insulation was 15 and 4 heads higher than in the premise without elements of heat insulation.

Table 3. Monitoring of ethological indicators during the period of low temperatures

Hours	Easy-to-assemble premises (n=88)				Easy-to-assemble premises with elements of heat insulation (n=85)			
	Air temperature, °C	Lay	Stand	Consume feed and drink water	Air temperature, °C	Lay	Stand	Consume feed and drink water
00.00	-11.7	69	11	8	-8.5	75	6	4
02.00	-12.3	57	26	5	-9.2	60	19	6
04.00	-12.7	50	22	16	-9.8	51	8	26
06.00 [#]	-12.4	–	–	–	-9.5	–	–	–
08.00 [‡]	-11.2	6	17	65	-8.9	4	12	69
10.00	-9.5	22	20	46	-7.1	37	9	39
12.00	-6.2	41	14	33	-6.0	44	5	36
14.00	-5.9	43	17	28	-4.8	44	11	30
16.00 [#]	-7.1	–	–	–	-5.3	–	–	–
18.00 [‡]	-8.4	4	23	61	-6.1	3	15	67
20.00	-10.2	39	15	34	-7.0	43	6	36
22.00	-10.8	51	8	29	-7.9	57	3	25

Note: # – periods of cows' milking; ‡ – time of forage distribution

Rest of cows in the lying position together with feed consumption is the main ethological indicators, the value of which indicates both positive and negative signs of housing technologies. Data do not coincide with the data of C. Muller [30] and A.D. Fisher [31], who report that at low temperatures the duration of lying cows decreased. The results of study coincide with the data of D.C. Adams, who found that at low temperatures, both feed activity and the duration of food intake decrease slightly [32]. However, M. Vaculikova in their studies conducted in the Czech Republic report about increase in the number of cows lying in periods of lower temperatures [33]. D. Lovarelli in the study conducted in northern Italy (Lombardy) also indicate an increase in the duration of rest in lying position in cows during periods of low temperatures (2.56-10.14°C) compared to the thermo-neutral period [34].

CONCLUSIONS

The use of polycarbonate wall heat insulation elements had a positive effect on the microclimate in the premises

during the period of low temperatures. The average daily air temperature in the room was 3.2 and 8.8°C higher compared to the temperature in the similar room without the use of heat insulation elements and the environment. The wind speed during the period of low temperatures was lower by 0.18 and 11.04 m/s, respectively, in comparison with the values of the environment and premises without heat insulation elements. Heat insulation of the walls influenced on the temperature under the lying cow (+1.8°C), energy outgoings for thermo-regulation (-1.93 MJ) and the number of cows that lay in the period of the lowest temperatures (+3.23-9.83%) compared to the barn without heat insulation elements. It was found that in the premise with heat insulation elements, the average WCT value was 4.27°C higher than in the premises without heat insulation elements. In premise with heat insulation elements, the CSI value was 80.37 MJ/m²/h lower than in the premise without the use of heat insulation elements.

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Поведінка та енергетичні втрати у корів упродовж періоду низьких температур

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Анотація. У тваринництві України за останні 20 років активно впроваджуються легкозбірні приміщення для утримання молочної худоби. Проте в умовах помірного клімату (з чотирма чітко вираженими сезонами року) питання мікроклімату, витрат енергії тваринами та їхньої поведінки упродовж холодного періоду року за утримання у таких приміщеннях повністю не вивчені. Метою цієї роботи було вивчити вплив використання елементів утеплення бокових штор у легкозбірному корівнику протягом періоду низьких температур на показники мікроклімату, витрат енергії на терморегуляцію та поведінку корів. Дослідження проводили у центральній частині України (Київська область) протягом січня-лютого (29–43 дні року) 2021 року. Цей період характеризувався низькими середньодобовими температурами $-12,2$ – $-18,7$ °C сильними поривами вітру та щоденними опадами у вигляді снігу. Для досліджень використовували два легкозбірних корівника на 400 голів. Параметри приміщень (ДхШхВ): $150 \times 32 \times 10,5$ м. Перший без використання елементів утеплення штор, а другий аналогічний з елементами утеплення. Встановлено, що використання елементів утеплення стін із полікарбонату позитивно вплинуло на показники мікроклімату у приміщенні протягом періоду низьких температур. Показники середньодобової температури повітря у приміщенні були на $3,2$ та $8,8$ °C вищими порівняно з температурою в аналогічному приміщенні без використання елементів утеплення та навколишнього середовища. Швидкість руху вітра також відрізнялась на $0,18$ та $11,04$ м/с відповідно. До того ж утеплення стін вплинуло на показник температури під лежачою корою (+ $1,8$ °C), витрати енергії на терморегуляцію ($-1,93$ МДж) та кількість корів, котрі лежали у період максимально низьких температур (+ $3,23$ - $9,83$ %) порівняно з приміщенням без елементів утеплення. При цьому показники температури матраців були вищими від середньої добової температури навколишнього середовища лише на $0,1$ °C у приміщеннях без утеплення, а у приміщеннях з елементами утеплення на $0,2$ °C. Різниця температури матраців між приміщеннями була суттєвою: + $3,3$ °C у приміщенні з елементами утеплення порівняно з приміщенням без утеплення.

Ключові слова: молочна худоба, холодний стрес, легкозбірні приміщення, вітро-холодовий індекс, холодо-стресовий індекс

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Evaluation of Bulls and Related Groups of the Jersey Breed on Dairy Productivity and Reproductive Capacity of Offspring

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Abstract. The article presents the results of research on the influence of paternal origin and belonging to a related group on the level of milk productivity of cows and the reproductive capacity of Jersey cows in the farm "Dan-Milk" of the Zhytomyr Region. The purpose of this study is to establish the influence of paternal origin and belonging to a related group on the level of milk productivity and reproductive capacity parameters of Jersey cows. The study established a substantial level of differentiation in the main economically useful features between groups of half-sisters by father. The best quantitative indicators of milk productivity were noted among the daughters of bulls DJ Jante 302761 ($P < 0.001$) and Headline 114114336 ($P < 0.001$), the worst indicators – among daughters of Karl 67037285. The highest indicators of fat and protein content in milk were noted in the cows bred from the bull Legal 61929249, the lowest – from the bull Karl 67037285. The influence of the origin of cows by father on the variability of milk yield and yield of milk fat and protein was 20.3–30.3% (up to $P < 0.001$), the content of fat and protein in milk decreased to 13.2–20.0% ($P < 0.01$ and $P < 0.05$), and according to the reproductive capacity features – to 7.8–19.0% with an unreliable level of statistical significance. Prepotent as to milk yield are bulls Legal 61929249 and Headline 114114336, as to the content and yield of milk protein – Legal 61929249. Cows of the related group bred from the bull Observer 553236 are characterised by the highest milk yield and yield of milk fat and protein for both the first and best lactation, and cows of the related group bred from Surville 604694 are characterised by the worst yield. The influence of belonging to a related group on the studied features was several times lower (0.2–10.5%) compared to the influence of paternal origin. With an increase in the milk yield of cows over the first lactation, there is a stable and substantial decrease in the reproductive capacity coefficient due to the lengthening of the service period between the first and second calving. Such natural antagonism does not imply the goal of increasing the duration of the service period to obtain maximum milk yields for firstborn cows, since this will lead to a decrease in the yield of calves and render timely replenishment of the herd impossible. It is optimal to milk the firstborn up to 8 tonnes over 305 days of lactation while maintaining a satisfactory reproductive level

Keywords: Jersey cattle, bull, short line, yield, reproduction, consolidation



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INTRODUCTION

Jersey cattle are described by high productive qualities and are the world's best dairy breed in terms of fat and protein content in milk. This breed is quite common in England, New Zealand, Australia, Denmark, and several other countries [1-3]. The world has accumulated a certain positive practice of purebred breeding of Jersey cattle and its cross-breeds with other dairy breeds [4; 5]. The Jersey breed has been a source of valuable heredity, which determines exceptionally high levels of fat and protein content in milk and payment for feed with products, which depends on the correct choice of the breeding bull [4; 6].

The use of biotechnological methods of sperm cryopreservation and artificial insemination substantially expands the opportunities for unleashing the potential of breeding bulls of any breed. One breeding bull can yield over 50 thousand offspring, while high-value cows can yield 7-10 offspring in a lifetime. The decisive role in the breeding process belongs precisely to breeding bulls, since they account for about 90% of the breeding effect [7].

The extensive use of improver bulls evaluated by the offspring allows creating highly productive herds, consolidated in terms of milk productivity, fertility, and duration of economic use. Therewith, breeding bulls are described by unequal stability of transmitting economically useful features to their daughters in their certain mutual combination, and even more so – in the desired one [8; 9].

Current trends in milk production require constant work to improve the genetic potential of cattle, which is achieved by increasing the level of milk yield, as well as its fat and protein content. Animals with modern milk production technology should have good reproductive capacity and long-term productive use. To achieve these goals, modern breeding programmes focus on functional compliance and productive life of the cow. One of the most effective methods of improving the breeding and productive qualities of dairy cattle is the use of prepotent improver bulls [10; 11].

Important elements of the intra-breed breeding structure are lines or related groups. The dynamism and replacement of some genealogical formations of the breed with others that are more promising and more valuable in breeding terms allows adjusting the breeding process with each herd individually. The development and improvement of any breed is largely conditioned upon its genealogical structure, the use of bulls from different related groups. Breeding along lines is considered the highest form of stock breeding and one of the methods of genetic improvement of herds and breeds. It enables an effective use of breeding bulls with high breeding value, which steadfastly transmit the desired manifestation of economically useful features to their offspring [12-14].

The purpose of this study is to establish the influence of paternal origin and belonging to a related group (short line) on the level of milk productivity and reproductive capacity parameters of Jersey cows.

MATERIALS AND METHODS

The object of this study is population-genetic patterns of inheritance of economically useful features of Jersey cows. The subject of this study is indicators of milk productivity and reproductive capacity of cows.

The study was conducted at the farm "Dan-Milk" of the Zhytomyrska Oblast. The farm fully maintains livestock and breeding records, and has implemented an automated information system called Uniform Agri. Cows are milked at the "Parallel" milking unit. The cattle are housed in yards with rest boxes. Diets are developed depending on the physiological state and productivity of cattle.

The genealogical structure of the herd is represented by the offspring of a considerable number of breeding bulls of the Jersey breed. Among the breeding stock imported from Denmark, the most numerous were the groups of half-sisters bred from bulls Headline 114114336 ($n=55$), Legal 61929249 ($n=15$), DJ Jante 302761 ($n=15$), Karl 67037285 ($n=20$), and Vernon 115863998 ($n=28$). The vast majority of cows and heifers are genealogically assigned to related groups bred from bulls Fallneva 593883, Surville 604694, and Observer 553236, represented by the offspring of at least three breeding bulls.

Milk productivity was recorded by performing control milking (every decade during the first three months and monthly until the end of lactation) and monthly determination of the fat and protein content (%) in milk (using the Ecomilk KAM-98.2A device). The study calculated lactation duration and milk production over 305 days, or reduced lactation.

The degree of phenotypic consolidation of related groups and prepotency of breeding bulls based on the studied features was evaluated according to the coefficients proposed by the authors of this study in [14] C_1 , C_2 , C_{avg} with their calculation using the following formulas:

$$C_1 = 1 - \sigma_g / \sigma_h, \quad C_2 = 1 - Cv_g / Cv_h \quad (1)$$

$$C_{avg} = (C_1 + C_2) : 2 \quad (2)$$

where σ_g and Cv_g are the standard deviation and variability coefficient of the estimated group of animals for a particular feature; σ_h and Cv_h are the standard deviation and variability coefficient of the general population (herd).

The degree of influence of various factors (paternal origin, belonging to a related group, milk yield level) on economically useful features was determined through the correlation of factorial and total variances using single-factor analysis of variance. Three standard levels of statistical significance were indicated using alphabetic superscripts (^a – $P < 0.05$, ^b – $P < 0.01$, ^c – $P < 0.001$).

Calculations were performed using mathematical statistics methods using the STATISTICA-13.0 software package on a personal computer.

RESULTS AND DISCUSSION

Breeding indices in bull catalogues do not always coincide with the results of evaluation in farm conditions [15-17].

Breeding progress can be achieved proceeding exclusively from the evaluation results of breeding bulls in the conditions of a particular herd. Regularities of correlated variability of features in the cows bred from breeding bulls allow identifying improvers both in terms of milk productivity and reproductive capacity [9; 12].

The farm "Dan-Milk" has established an intensive milk production technology, which ensures increasing the productivity of cows while neglecting extensive production factors, namely increasing the number of breeding stock at the expense of its herd replacements. The study

established that the intergroup difference between half-sisters after the father was not identified only regarding lactation duration, which is quite natural because this feature is largely determined by paratypical factors. Similar patterns were established in the studies of other Ukrainian and foreign authors [13; 18; 19].

In the herd of the farm "Dan-Milk", the study established a substantial differentiation level in the main economically useful features between groups of cows (paternal half-sisters) bred from different bulls (Table 1).

Table 1. Reproductive capacity and productivity of cows bred from different bulls

Feature	Group of half-sister cows bred from:					
	Headline 114114336	Legal 61929249	DJ Jante 302761	Karl 67037285	Vernon 115863998	
First lactation						
Number of cows monitored	55	15	15	20	28	
Duration of periods, days:	Second pregnancy	279.9±0.45	278.8±0.80	278.4±1.20	278.1±1.14	280.3±0.57
	Service period	142.4±9.25	147.6±19.96	129.5±15.69	133.2±13.47	153.8±19.22
	Lactation	361.3±9.28	365.2±19.70	348.1±15.48	352.5±13.88	372.7±18.92
	Interlactation period	61.0±0.63	61.2±0.92	59.7±1.14	58.8±1.08	61.4±0.93
	Between I and II calving	422.3±9.23	426.4±19.90	407.8±15.45	411.4±13.72	434.1±19.31
Reproductive capacity coefficient (RCC)	0.88±0.017	0.89±0.038	0.91±0.031	0.90±0.029	0.88±0.035	
Milk yield, kg	Over lactation	9738±286.7 ^c	9044±518.2 ^b	10008±808.5 ^b	7240 ± 310.3	9556±516.6 ^c
	Over 305 days	8217±206.4 ^c	7433±301.6 ^c	8579±531.3 ^c	6211±137.2	7800±301.8 ^c
Milk fat:	%	4.70±0.073	4.76±0.122	4.72±0.150	4.43±0.131	4.58±0.066
	kg	388.9±13.6 ^c	353.8±17.11 ^c	401.9±25.84 ^c	273.9±7.52	357.4±14.91 ^c
Milk protein:	%	3.73±0.043	3.74±0.071	3.74±0.089	3.55±0.096	3.69±0.058
	kg	308.0±9.17 ^c	278.7±12.86 ^c	317.9±19.19 ^b	219.5±5.95	287.9±11.96 ^c
Higher lactation						
Milk yield over 305 days, kg	8660±242.3 ^c	7890±369.5 ^b	9419±582.5 ^c	6790±149.8	8420±347.9 ^c	
Milk fat:	%	4.63±0.081	4.92±0.097 ^a	4.66±0.213	4.94±0.120 ^a	4.71±0.126
	kg	399.3±12.45 ^c	389.2±20.73 ^b	431.9±27.47 ^b	336.0±12.63	392.1±15.60 ^c
Milk protein:	%	3.68±0.051	3.85±0.047 ^b	3.67±0.109	3.87±0.075 ^a	3.70±0.066
	kg	317.2±9.41 ^c	303.6±14.75 ^b	343.5±21.48 ^b	263.1±7.94	310.6±12.91 ^c

Notes: ^a – $P < 0.05$, ^b – $P < 0.01$, ^c – $P < 0.001$

In general, a statistically reliable difference in various levels of significance (from $P < 0.05$ to $P < 0.001$) in milk productivity features between the cows of the best bulls and the coevals of a worse breeder was found in 17 cases out of 35, which is 49% of the total number of compared pairs.

Milk productivity is the main breeding feature of dairy cows, which forms an integral component in the

calculation of selection indices [14; 20]. Therefore, the study investigated the effect of paternal ancestry on milk productivity features. A general biological pattern was discovered – intergroup differentiation of cows of individual breeder bulls. Moreover, the highest milk yield is associated with the lowest indicators of fat and protein content in milk, which is consistent with literature data – an increase in milk yield often entails a decrease in fat and

protein content in milk and reproductive capacity [21-23]. The best milk productivity is noted among the cows bred from bulls DJ Jante 302761, Headline 114114336 and Vernon 115863998, who in terms of milk yield, milk fat and protein yield for the first and best lactation reliably (up to $P < 0.001$) outperformed their coevals bred from Karl 67037285, the worst bull according to these features. In particular, the milk yield for the first lactation of the cow bred from DJ Jante 302761 dominated its coevals from Karl 67037285 by 2768 ± 866.0 kg or 38.2%, over its first 305 days – by 2368 ± 548.7 kg or 38.1%, according to the yield of milk fat over 305 days of the first lactation – by 128.0 ± 26.91 kg or 46.7%, milk protein – by 98.4 ± 33.58 kg or 44.8%. Over 305 days of better lactation, this milk yield advantage reached 2629 ± 601.5 kg or 38.7%, milk fat yield – 95.9 ± 30.23 kg or 28.5%, protein yield – 80.4 ± 22.90 kg or 30.6%.

According to the quality indicators of milk, the intergroup difference for various lactation periods turned out to be multidirectional. As for fat and protein content in milk over 305 days of the first lactation of the cow bred from the worst breeder in terms of firstborn's milk yield Karl 67037285 are inferior to their coevals from the rest of the compared bulls at a close to statistically significant level. In particular, the cows bred from Headline 114114336 are superior in fat content by $0.27 \pm 0.15\%$ and in protein content – by $0.18 \pm 0.105\%$ for $P < 0.1$. But on the other hand, for the best lactation in terms of milk yield, cows bred from Karl 67037285 have the highest content of fat and protein in milk with a statistically significant ($P < 0.05$) difference over their coevals from Headline 114114336. Among the firstborns, the cow bred from the bull Legal 61929249 is characterised by the highest content of fat and protein in milk. In most cases, comparison of group averages confirms the inverse correlation variability of quantitative and qualitative features of dairy productivity of cows.

The highest indicators of fat and protein content in milk were noted in the cows bred from the bull Legal 61929249, the lowest – from the bull Karl 67037285. That is, it was not possible to simultaneously identify the improver in both qualitative and quantitative features because, quite naturally, an increase in the level of milk yield entails a decrease in milk quality features. Therewith, the cows bred from the bull Karl 67037285 are described by both the lowest milk yield and the lowest fat and protein content in milk, which indicates the inexpediency of reusing this bull ($P < 0.05$, $P < 0.01$, $P < 0.001$). The results obtained indicate a substantial difference between the cows bred from different bulls of the farm "Dan-Milk" and allow identifying the best concerning milk

productivity. The best indicators of milk productivity were noted among the cows bred from bulls DJ Jante 302761 and Headline 114114336 of the Observer 553236 line. Therefore, it is promising to use breeding bulls of this line in the selection plans for the breeding stock of the herd under study, provided that close inbreeding is avoided.

The best indicators of milk productivity for higher lactation were noted among the cows bred from bulls DJ Jante 302761 and Headline 114114336, who reliably ($P < 0.001$) outperformed the cows bred by Karl 67037285 in terms of milk yield (by 2.628 and 1.870 kg, respectively), milk fat (by 95.9 and 63.3 kg) and protein (by 80.4 and 54.1 kg). In turn, the cows bred from the bull DJ Jante 302761 are also reliably superior ($P < 0.05$) to the cows bred from the bull Legal 61929249 in terms of milk yield by 1.528 kg. The cows bred from the bull Headline 114114336 had the lowest rates of fat and protein in milk, demonstrating general biological feedback between milk yield and fat content in milk. Therewith, they were inferior ($P < 0.05$, $P < 0.01$) to the cows bred from the bulls Legal 61929249 (0.29% against 0.17%) and Karl 67037285 (0.31% against 0.19%) in these features.

Apart from milk productivity, the authors of this study have investigated the features of reproductive capacity of the offspring of various breeding bulls as an essential aspect of the development of modern dairy cattle breeding. Several authors [24-27] report an increase in the duration of lactation and a deterioration in the reproductive capacity of cows due to the lengthening of the service period. This is quite natural because animals need more time to restore the functions of the genitals and the normal course of their sexual cycle. The dependence of reproductive qualities on paratypical factors is confirmed by other authors [28-30]. This study also confirms the low level of genetic determination of cows' reproductive capacity features. This is conditioned upon the lower heritability of these features compared to dairy productivity.

There was no statistically significant difference between the paternal half-sister groups in terms of reproductive features ($P > 0.05$). However, the cows bred from the bull DJ Jante 302761 combine high milk productivity with satisfactory reproductive features (Table 1), which is confirmed by the result of its assessment according to the quality of offspring (6.031 cows, the reliability of the assessment is 99%, NTM – 5), given by the Jersey Cattle Association [31; 32]. That is, this breeder is an improver of milk yield and reproductive capacity.

Univariate analysis of variance confirms the effect of the parental origin of cows on individual features of reproductive capacity investigated by comparison of group averages (Table 2).

Table 2. Impact of ($\eta_x^{2\pm S.E., \%}$) origin by father on the studied features of cattle

Feature		F.	P	$\eta_x^{2\pm S.E., \%}$
Number of degrees of freedom:	Factorial		21	
	Random		145	
First lactation				
Duration of periods, days:	Second pregnancy	1.62	0.0517	19.0±0.14
	Service period	0.72	0.8066	9.5±0.14
	Lactation	0.71	0.8224	9.3±0.14
	Interlactation period	1.21	0.2471	15.0±0.14
	Between I and II calving	0.72	0.8110	9.4±0.14
Reproductive capacity coefficient		0.58	0.9237	7.8±0.14
Milk yield, kg	Over lactation	1.76	0.0286	20.3±0.14
	Over 305 days	3.00	<0.0001	30.3±0.13
Milk fat:	%	1.05	0.4040	13.2±0.14
	kg	2.53	<0.0001	26.8±0.13
Milk protein:	%	1.47	0.0951	17.6±0.14
	kg	2.97	<0.0001	30.0±0.13
Higher lactation				
Milk yield over 305 days, kg		2.35	0.0010	25.4±0.14
Milk fat:	%	1.73	0.0321	20.0±0.14
	kg	1.60	0.0558	18.8±0.14
Milk protein:	%	1.60	0.0568	18.8±0.14
	kg	1.79	0.0247	20.6±0.14

Notes: *F* is Fisher's criterion, *P* is probability

The basis of selection is to assign the evaluated improver bulls to the breeding stock to obtain highly productive offspring. In most cases, the conducted studies revealed a statistically significant level of intergroup differentiation of paternal half-sisters based on the features of cows' milk productivity, which proves the effectiveness of breeding Jersey cattle by using the identified improvers to obtain highly productive offspring in the next generation.

A higher (20.3-30.3%) and statistically significant (up to $P < 0.0001$) level of heredity was observed in the firstborn by milking and yield of milk fat and protein, as well as by milking the best lactation over 305 days. As for fat and protein content in milk, the strength of the

paternal influence decreases to 13.2-20.0% with a lower level of confidence ($P < 0.1$ and $P < 0.05$). According to the reproductive capacity features, an even lower level of heredity was established (7.8-19.0%) with an unreliable level of statistical significance. Greater breeding value is represented by the improver bulls with stable transmission of breeding qualities to offspring (prepotency), which is realised through a relative narrowing of variability (consolidation) in groups of paternal half-sisters [33; 34].

According to the features under study, the breeders used in the herd are described (Table 3) according to varying degrees of prepotency (up to $C = 0.684$) or are yield (up to $C = -0.336$).

Table 3. Consolidation of paternal half-sister groups (breeder prepotence)

Feature	Coefficient	Breeder prepotence:						
		Headline 114114336	Legal 61929249	DJ Jante 302761	Karl 67037285	Vernon 115863998		
Duration of periods, days:	Second pregnancy	C_1	0.133	0.011	-0.215	-0.150	0.206	
		C_2	0.136	0.010	-0.219	-0.155	0.209	
		C_{avg}	0.134	0.011	-0.217	-0.152	0.207	
	Service period	C_1	0.104	-0.169	0.204	0.316	-0.332	
		C_2	0.104	-0.128	0.124	0.270	-0.233	
		C_{avg}	0.104	-0.148	0.164	0.293	-0.282	
	Interlactation period	C_1	-0.026	0.092	0.019	0.069	-0.096	
		C_2	-0.014	0.106	0.010	0.046	-0.076	
		C_{avg}	-0.020	0.099	0.015	0.058	-0.086	
	between I and II calving	C_1	0.104	-0.164	0.218	0.305	-0.336	
		C_2	0.106	-0.150	0.191	0.288	-0.297	
		C_{avg}	0.105	-0.157	0.205	0.296	-0.317	
Coefficient of reproducibility	C_1	0.089	-0.204	0.149	0.209	-0.288		
	C_2	0.083	-0.206	0.168	0.218	-0.302		
	C_{avg}	0.086	-0.205	0.158	0.213	-0.295		
Over 305 days of the first lactation	Milk yield, kg	C_1	0.061	0.172	-0.263	0.674	0.020	
		C_2	0.130	0.152	-0.120	0.600	0.044	
		C_{avg}	0.095	0.162	-0.192	0.637	0.032	
	Milk fat	%	C_1	-0.082	-0.092	-0.164	-0.016	0.304
			C_2	-0.068	-0.065	-0.144	-0.064	0.295
			C_{avg}	-0.075	-0.079	-0.154	-0.040	0.300
		kg	C_1	0.050	0.047	-0.031	-0.117	0.075
			C_2	0.058	0.059	-0.020	-0.165	0.074
			C_{avg}	0.054	0.053	-0.025	-0.141	0.075
	Milk protein	%	C_1	-0.096	0.169	-0.087	0.684	0.143
			C_2	0.002	0.168	0.042	0.591	0.151
			C_{avg}	-0.047	0.168	-0.023	0.637	0.147
		kg	C_1	-0.002	0.153	-0.095	0.660	0.068
			C_2	0.083	0.143	0.029	0.564	0.087
			C_{avg}	0.041	0.148	-0.033	0.612	0.077

As for pregnancy duration, a notable prepotence was observed in breeder bulls Head-line 114114336 and Vernon 115863998, while DJ Jante 302761 and Karl 67037285 were yield. According to the coefficient of reproducibility, the duration of the service period between 1st and 2nd calving, the bulls Karl 67037285 and DJ Jante 302761 can be attributed to prepotent, while Vernon 115863998 and Legal 61929249 – to yield ones. In terms of the duration of the interpregnancy period,

all producers had low prepotency coefficients, which confirms its low genetic conditionality from the standpoint of the planned regulation of the cows dry-off by the livestock owner.

According to milk yield of the firstborn, the improver bull DJ Jante 302761 is characterised by a higher-than-average phenotypic variability of this feature in cows bred from it, that is, it turned out to be yield. Positive coefficients of milk yield consolidation are inherent

in groups of paternal half-sisters bred from bulls Legal 61929249 and milk yield improver Headline 114114336, which gives an additional selection advantage to the latter. According to the content and yield of milk protein, the bull Legal 61929249 can be considered prepotent, and according to the content and yield of milk fat and protein – milk yield improver Vernon 115863998. The highest level of prepotency in terms of milk yield, milk protein content and yield, as well as the duration of the service period between the 1st and the 2nd calving, was observed in bull Karl 67037285. However, given the lowest milk yield of its cows for the first and highest lactation and the lowest content and yield of milk fat and protein of the firstborn (Table 1), that is, the high prepotence of the aggravator, makes it highly undesirable to continue using this breeder in the herd under study. According to the reproductive features, the breeding bull DJ Jante 302761 is recommended for further use in the herd, which produces an improving effect on RCC, the duration of the service period between calving with a distinctive level of prepotency.

Phenotypic and genetic specificity constitutes an important component of testing and further genetic progress of breeds and intra-breed formations (lines, families, types) [33]. The study established a slightly lower, compared to the paternal origin, but a significant effect of belonging to a related group on the features of milk productivity for both the first and highest lactation. The obtained results are consistent with the literature data on the statistically significant influence on the economically useful features of paternal origin and linear affiliation on the variability of features of live weight, milk productivity and reproductive capacity of cows [34; 35].

Of particular interest is the average level of prepotency of breeding bulls used in the herd according to individual characteristics. The average level of consolidation of the five investigated groups of paternal half-sisters for the duration of the second pregnancy was -0.003, the service period – 0.026, the interlactation period – 0.013, the interpregnancy period – 0.026, and the reproductive capacity coefficient – -0.009. On average, according to these features, which to a certain extent describe the reproductive capability of animals, the prepotence of the evaluated producers was 0.011. This

confirms the low level of consolidation of intra-breed selection groups according to reproductive features. According to the milk productivity features, the degree of consolidation of the related groups under study, as well as groups of paternal semi-sisters, was higher. According to the milk yield of firstborns, the average level of prepotency of the offspring was 0.147, according to the fat content in milk – -0.010, its yield – 0.003, protein content in milk – 0.176, milk protein yield – 0.169 (Table 3). On average, per five milk productivity features of cows over 305 days of the first lactation, the level of consolidation of groups of paternal half-sister cows was 0.097, which exceeded that for reproductive features by 8.8 times. This can be explained by the priorities of selection for dairy productivity.

A certain proportion of variability in the breed should be determined by intergroup variability between homogeneous and differentiated structural elements of the breed. The offspring of a certain breeder belonging to lines or certain related groups should be described not only by a common origin, but also by the uniformity of the manifestation of economically useful features [14; 15; 17]. Therefore, when evaluating cows of a particular herd according to milk productivity features, it is necessary to consider their genealogical structure [14].

Among the related groups whose breeders were used in the herd under study, the most numerous in terms of breeding stock were the offspring groups bred from progenitor bulls Fallneva 5938833, Observer 553236, and Surville 604694. The comparison of group averages established a statistically significant level of intergroup differentiation according to features of milk productivity, and a considerably lower level, unreliable in all cases – according to considered features of reproductive capacity (Table 4). Cows of the related group bred from Observer 553236 are characterised by the highest milk yield and yield of milk fat and protein for both the first and best lactation. They outperformed cows of the worst related group bred from Surville 604694 for the first lactation in milk yield by 1321±281.0 kg or 19.1% ($t_d=4.70$, $P<0.001$), by milk fat yield – by 68.2±16.79 kg or 21.3% ($t_d=4.06$, $P<0.001$), protein – by 54.0±12.30 kg or 21.3% ($t_d=4.39$, $P<0.001$).

Table 4. Reproductive capacity and productivity of cows of different related groups

Feature	Related Group:			
	Fallneva 5938833	Observer 553236	Surville 604694	
Number of cows monitored	35	74	35	
First lactation				
Duration of periods, days:	Second pregnancy	280.1±0.52	279.5±0.43	278.5±0.68
	Service period	154.0±16.91	137.8±7.62	141.5±12.68
	Interlactation period	60.9±0.84	60.6±0.53	60.2±0.72
	Between I and II calving	434.1±16.95	417.3±7.60	420.0±12.70
Reproductive capacity coefficient	0.88±0.03	0.89±0.01	0.89±0.02	

Table 4, Continued

Feature	Related Group:				
	Fallneva 5938833	Observer 553236	Surville 604694		
Number of cows monitored	35	74	35		
First lactation					
Over 305 days:	Milk yield, kg	7559±262.4 ^a	8230±189.3 ^c	6909±207.7	
	Milk fat:	%	4.58±0.07	4.69±0.06 ^b	4.62±0.09
		kg	346.0±12.88	387.8±11.52 ^a	319.6±12.22
	Milk protein:	%	3.68±0.06 ^a	3.73±0.04 ^b	3.66±0.06
		kg	278.1±10.40	307.3±7.98 ^b	253.3±9.18
Higher lactation					
Over 305 days:	Milk yield, kg	8183±297.7 ^a	8768±218.3 ^c	7419±237.3	
	Milk fat:	%	4.69±0.12	4.64±0.08 ^b	4.93±0.07
		kg	380.6±14.33	403.8±10.97 ^a	366.4±13.63
	Milk protein:	%	3.68±0.06 ^a	3.68±0.05 ^b	3.86±0.04
		kg	300.6±11.58	320.8±8.33 ^b	286.2±9.61

Notes: ^a – $P < 0.05$, ^b – $P < 0.01$, ^c – $P < 0.001$

For higher lactation – by 1349±322.4 kg or 18.2% ($t_d=4.18$, $P < 0.001$), 37.4±17.50 kg or 10.2% ($t_d=2.14$, $P < 0.05$), 34.6±12.72 kg or 12.1% ($t_d=2.72$, $P < 0.01$). As for fat and protein content in milk for the first lactation, the difference between cows of these related groups was insignificant (+0.07%), and for the best milk lactation, animals of the related group bred from Surville 604694, on the contrary, prevailed over coevals of the related group bred from Observer 553236 in terms of fat content by 0.29±0.106% ($t_d=2.74$, $P < 0.01$) and protein – by 0.18±0.064% ($t_d=2.81$, $P < 0.01$). Cows of the related group bred from Fallneva 5938833 occupied an intermediate position in most features of milk productivity for the first and highest lactation.

Cows of related groups bred from Fallneva 593883 and Observer 553236 scored the best indicators of milk productivity. There was no essential difference in the features of milk productivity between them, which can be explained by the commonality of their origin (Fallneva 593883 is bred from Observer 553236). This gives grounds to recommend using breeders of both related groups specified. Cows of the related group bred from Observer 553236 have the shortest service and interpregnancy periods and a higher reproductive capacity coefficient, while cows of the related group bred from Fallneva 593883 have longer service and interpregnancy periods, and a lower reproductive capacity coefficient. But the intergroup difference in reproductive features was non-essential and did not reach a statistically significant level.

Among the cows of the related group bred from Observer 553236, the most numerous were the offspring of Headline 114114336 and DJ Jante 302761 bulls, in the related group bred from Fallneva 593883 – the breeder bull Vernon 115863998, and in the related group bred

from Surville 604694 – breeder bulls Karl 67037285 and Legal 61929249.

Variance analysis confirms the non-essential effect of belonging to a related group on the reproductive features established by comparison of group averages (Table 5). According to these signs, only the effect on the phenotypic variability of pregnancy duration was reliable or approached such – over the duration of the interlactation period. Belonging to a related group also has a low (2.0-2.4%) and unreliable ($P > 0.1$) effect on the fat and protein content in milk for both the first and best lactation.

The specified genetic factor has a more substantial (7.7-10.5%) and statistically significant ($P < 0.01$... $P < 0.001$) effect on milk yield, milk fat and protein yield in firstborn cows. According to these features, for higher lactation, the effect decreases to 3.0 ... 6.5%. In general, the influence of belonging to a related group on the features under study was several times lower compared to the influence of paternal origin.

The main feature of a line or related group is the consolidation inherent in their representatives regarding the economically useful features due to kinship and directional selection, which makes them different from others to a certain extent [16]. The authors of this study have established that the values of the coefficients of phenotypic consolidation of animals of various related groups of the herd under study are described mainly by positive values with slight variability. Ukrainian authors have established the influence of leading genealogical formations on the degree of phenotypic consolidation coefficients, which directly affects breeding work with the herd and provides the necessary uniformity and trend of desired traits [16; 36].

Table 5. Impact of ($\eta_x^2 \pm S.E., \%$) belonging to a related group on the variability of features in cattle

Feature		F.	P	$\eta_x^2 \pm S.E., \%$
Number of degrees of freedom:	Factorial		2	
	Random		151	
First lactation				
Duration of periods, days:	Second pregnancy	5.47	0.0051	6.8±0.01
	Service period	0.17	0.8409	0.2±0.01
	Lactation	0.19	0.8302	0.2±0.01
	Interlactation period	2.89	0.0587	3.7±0.01
	Between I and II calving	0.28	0.7585	0.4±0.01
Reproductive capacity coefficient		0.17	0.8479	0.2±0.01
Milk yield, kg	Over lactation	6.28	0.0024	7.7±0.01
	Over 305 days	8.41	0.0003	10.0±0.01
Milk fat:	%	1.52	0.2230	2.0±0.01
	kg	7.19	0.0010	8.7±0.01
Milk protein:	%	1.89	0.1548	2.4±0.01
	kg	8.82	0.0002	10.5±0.01
Higher lactation				
Milk yield over 305 days, kg		5.28	0.0061	6.5±0.01
Milk fat:	%	1.77	0.1741	2.3±0.01
	kg	2.3	0.1033	3.0±0.01
Milk protein:	%	1.72	0.1818	2.2±0.01
	kg	3.21	0.0432	4.1±0.01

Notes: F is Fisher's criterion, P is probability

A certain selection interest is the degree of consolidation of the evaluated related groups based on the features under study. It was established (Table 6) that on average, the related group Observer 553236 demonstrates the greatest consolidation ($C_{avg} = 0.058$), slightly lower – in the related group Surville 604694 ($C_{avg} = 0.038$), and the related group Fallneva 593883 demonstrates the intra-group variability even slightly higher ($C_{avg} = -0.008$) than the total variability across the herd. The degree of

phenotypic consolidation of the related groups under study substantially differs by groups of features describing the reproductive capacity or milk productivity. According to the reproductive features, the related group bred from Observer 553236 also demonstrates a higher level of consolidation ($C_{avg} = 0.084$), the smallest ($C_{avg} = -0.143$) – in the group bred from Fallneva 593883, and in the related group bred from Surville 604694 the intra-group phenotypic variability is almost identical to the total ($C_{avg} = 0.001$).

Table 6. Degree of phenotypic consolidation of related groups

Feature	Coefficient	Breeder prepotence:			
		Fallneva 5938833	Observer 553236	Surville 604694	
Duration of periods, days:	Second pregnancy	C_1	0.195	0.037	-0.049
		C_2	0.198	0.038	-0.051
		C_{avg}	0.196	0.038	-0.050
Duration of periods, days:	Service period	C_1	-0.310	0.142	0.018
		C_2	-0.212	0.113	0.011
		C_{avg}	-0.261	0.127	0.014

Table 6, Continued

Feature		Coefficient	Breeder prepotence:			
			Fallneva 5938833	Observer 553236	Surville 604694	
Duration of periods, days:	Interlactation period	C_1	-0.096	-0.009	0.058	
		C_2	-0.085	-0.003	0.057	
		C_{avg}	-0.090	-0.006	0.057	
	Between I and II calving	C_1	-0.311	0.145	0.017	
		C_2	-0.273	0.136	0.014	
		C_{avg}	-0.292	0.140	0.016	
Coefficient of reproducibility		C_1	-0.258	0.119	-0.034	
		C_2	-0.273	0.122	-0.030	
		C_{avg}	-0.266	0.121	-0.032	
Over 305 days of the first lactation	Milk yield, kg	C_1	0.047	0.000	0.246	
		C_2	0.041	0.076	0.169	
		C_{avg}	0.044	0.038	0.208	
	Milk fat	%	C_1	0.216	-0.087	-0.095
			C_2	0.206	-0.075	-0.100
			C_{avg}	0.211	-0.081	-0.097
		kg	C_1	0.172	-0.077	0.214
			C_2	0.153	0.017	0.129
			C_{avg}	0.162	-0.030	0.172
	Milk protein	%	C_1	0.018	0.013	-0.054
			C_2	0.014	0.021	-0.065
			C_{avg}	0.016	0.017	-0.059
		kg	C_1	0.093	-0.012	0.199
			C_2	0.081	0.072	0.109
			C_{avg}	0.087	0.030	0.154

As for dairy productivity, a higher level of consolidation was observed, on the contrary, in the related group Fallneva 593883 ($C_{avg}=0.104$), slightly lower – in the related group Surville 604694 ($C_{avg}=0.076$), and in the related group Observer 553236 it decreases on average to negative values ($C_{avg}=-0.005$). Therefore, with further expanded use of cows of the most productive related group Observer 553236, herd consolidation should not be expected according to milk productivity features. It can be achieved by searching for and using prepotent improvers among the producers of this related group.

Of certain interest is the average degree of consolidation of the related groups under study based on their separate features. For three related groups, the duration of the second pregnancy was 0.061, the service period – -0.040, the interlactation period – -0.013, the interpregnancy period – -0.045, and the reproductive capacity coefficient – -0.059.

On average, according to these reproductive features, the phenotypic consolidation amounted to -0.019. This confirms the low level of consolidation of intra-breed selection groups according to reproductive features. According to the milk productivity features, the degree of consolidation of the related groups under study, as well as groups of semi-siblings by father, was higher. The average milk yield of firstborn was 0.097, the fat content in milk – 0.011, its yield – 0.101, the protein content in milk – -0.009, the yield of milk protein – 0.090 (Table 6). On average, per five milk productivity features of cows over 305 days of the first lactation, the level of phenotypic consolidation of related groups was 0.058, which substantially exceeded that for reproductive features. The authors of this study tend to explain this by the priorities of breeding for dairy productivity.

An essential biological and at the same time economic criterion for the effectiveness of animals is their

reproductive capacity [37-39]. This is a complex feature that depends mainly on the duration of the service period and the generalising indicator – the reproductive capacity coefficient. It was proved that the factual parameters of the reproductive capacity of firstborn cows are

somewhat inferior to the optimal ones. Considering the established natural antagonism of the milk productivity and reproductive features, the study compared the group average features describing the reproductive capacity at different levels of milk yield of firstborns (Table 7).

Table 7. Reproductive capacity of Jersey cows with different milk yield of firstborns

Group according to milk yield of firstborns, kg	Number of cows monitored	Duration of the period, days:				Reproductive capacity coefficient
		II pregnancy	Service period	Interlactation period	Between I and II calving	
Up to 7,000	31	276.9±0.78	93.5±5.81	58.2±0.81	370.4±5.85	0.99±0.015
7,001-8,000	34	279.9±0.56 ^b	112.5±10.10	60.6±0.90	392.4±10.19	0.95±0.021
8,001-9,000	41	279.5±0.63 ^b	127.6±9.95 ^b	60.5±0.69 ^a	407.1±9.93 ^c	0.91±0.020 ^c
9,001-10,000	29	279.7±0.65 ^b	162.0±13.26 ^c	61.3±0.78 ^b	441.7±13.10 ^c	0.85±0.023 ^c
Over 10,000	32	279.8±0.61 ^b	219.7±13.93 ^c	60.9±0.64 ^a	499.4±13.79 ^c	0.75±0.020 ^c

Notes: ^a – $P < 0.05$, ^b – $P < 0.01$, ^c – $P < 0.001$

An increase in the duration of biological reproductive periods led to a decrease in the reproductive capacity coefficient. It was found that the increase in milk yield of cows during the first lactation practically does not affect the duration of pregnancy and the dry period, except for their smaller value in animals with milk yield up to 7,000 kg. This is conditioned upon the high biological constancy of the pregnancy duration and the planning of the duration of the interlactation period by the livestock owner. Therewith, a stable and substantial decrease in the reproductive capacity coefficient due to the lengthening of the service period between the first and second calving was confirmed. Starting with milking more than 8 tonnes, the deterioration of reproductive features in firstborns acquires a statistically significant level ($P < 0.01$... $P < 0.001$). Such natural antagonism does not imply the goal of increasing the duration of the service period to obtain maximum milk yields for firstborn cows. The authors of this study believe that it is optimal to milk the firstborn up to 8 tonnes over 305 days of lactation while maintaining a satisfactory reproductive level.

Notably, cows with the lowest milk yield level among the general sample were also described by a shorter pregnancy duration compared to more productive animals ($P < 0.01$, $P < 0.001$). With an increase in the milk yield level, there is a likely increase in the duration of biological reproduction periods (service and interpregnancy). It was established [40] that apart from the milk productivity level, the reproductive features of cows are affected by the management decisions of each particular husbandry. Similar conclusions were also obtained in studies by other authors [41].

Regression analysis confirmed a direct correlation

between the milk yield of cows (Y) and the duration of the service period (X), which is described by a linear equation of the form $y = 6443 + 18.3x$ (Fig. 1) by the coefficient of determination $R^2 = 0.974$. This equation describes 97.4% of cases. The presented histogram and graph illustrate a stable direct correlation between milk productivity and the reproductive capacity of cows. According to the established regression coefficient, the extension of the service period of cows by one day causes an increase in milk yield by 18.3 kg. The inverse regression equation (x over y) gives grounds to expect an extension of the service period by 29 days, with an increase in milk yield for every 1,000 kg. The trend line is reliable and demonstrates a high degree of approximation (coincidence) to the factual data, expresses the share of variation of the dependent variable determined by the correlation coefficient, i.e., how accurately the linear equation describes the data obtained in the experiment [42].

A linear model of milk yield changes over 305 days with an increase in the duration of the service period is also calculated. The equation has the form $y = 8107 - 3.5x$ for the determination coefficient $R^2 = 0.980$. This equation describes 98.0% of the sample cases.

As previously noted, increasing the milk yield for lactation by extending the service period cannot be considered a selection purpose, since this entails a decrease in the yield of calves and renders the timely herd replacement impossible. Variance analysis confirmed a substantial (up to 35.2%) and reliable ($p < 0.0001$) effect of milk yield of firstborn cows on the phenotypic variability of the duration of service and interpregnancy periods and the reproductive capacity coefficient (Table 8).

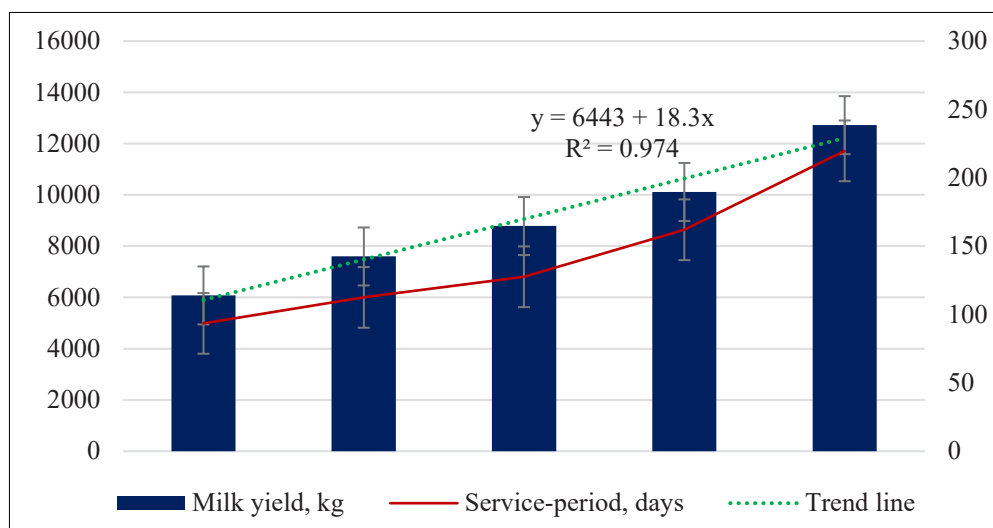


Figure 1. Correlation between milk yield of cows during lactation and the service period

Table 8. The strength of the milk productivity effect on the reproductive capacity of cows

Feature	F.	P	$\eta_x^2 \pm S.E., \%$	
Number of degrees of freedom:	Factorial	4		
	Random	162		
Duration of periods, days:	Second pregnancy	3.65	0.0071	8.3±0.02
	Service period	20.01	<0.0001	33.0±0.02
	Interlactation period	2.27	0.0637	5.3±0.02
	Between I and II calving	20.77	<0.0001	33.9±0.02
Reproductive capacity coefficient	21.97	<0.0001	35.2±0.02	

Notes: F is Fisher's criterion, P is probability

CONCLUSIONS

The substantial influence of breeding bulls on the economic utility features of the cows bred from them is proved, as evidenced by a statistically significant intergroup difference. Cows bred from DJ Jante 302761 ($P < 0.001$) and Headline 114114336 ($P < 0.001$) were described by the best quantitative indicators of milk productivity, while cows bred from Karl 67037285 were the worst. The highest indicators of fat and protein content in milk were noted in the cows bred from the bull Legal 61929249, the lowest – from the bull Karl 67037285. Paternal half-sisters bred from the bull Karl 67037285 are described by both the lowest milk yield and the lowest fat and protein content in milk, which indicates the inexpediency of further use of this bull ($P < 0.05$, $P < 0.01$, $P < 0.001$). A substantial intergroup difference between half-siblings and fathers was also confirmed by univariate analysis of variance – the strength of the effect on milk fat and protein yield was 20.3–30.3% (up to $P < 0.001$), for the content of fat and protein in milk – 13.2–20.0% ($P < 0.1$ and $P < 0.05$), for reproductive capacity features – 7.8–19.0% with an unreliable level of statistical significance.

Positive coefficients of potency for milking are inherent in bulls Legal 61929249 and milk yield improver Headline 114114336, which gives an additional selection advantage to the latter. According to the content and yield of milk protein, the bull Legal 61929249 can be considered prepotent, and according to the content and yield of milk fat and protein – milk yield improver Vernon 115863998. The highest level of prepotency for most features was the aggravator bull Karl 67037285, which makes it highly undesirable to continue using this breeder in the herd. The generalised consolidation coefficient for milk productivity features was 0.097, which is 8.8 times more than for reproductive features. This indicates the priority of selecting animals in this herd based on the features of milk productivity.

The study established a statistically significant level of differentiation of related groups according to features of milk productivity, and considerably lower level, unreliable in all cases – according to features of reproductive capacity. Cows of the related Observer 553236 group are characterised by the highest milk yield and

yield of milk fat and protein for both the first and best lactation, and cows of the related Surville 604694 group are characterised by the worst yield. The influence of belonging to a related group on the studied features was several times lower compared to the influence of paternal origin. The well-known antagonism between

dairy and reproductive dominants was proved – there is a stable and substantial decrease in the coefficient of reproductive capacity due to the extension of the duration of service period and the period between the first and second calving, with a simultaneous increase in the milk yield.

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**Оцінка плідників і споріднених груп джерсейської породи
за молочною продуктивністю та відтворювальною здатністю потомства**

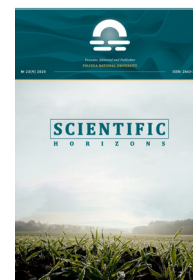
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Анотація. У статті наведено результати досліджень щодо впливу походження за батьком та належності до спорідненої групи на рівень молочної продуктивності корів і відтворювальної здатності корів джерсейської породи в умовах ДП «Дан-Мілк» Житомирської області. Метою наукової роботи є встановлення впливу походження за батьком та належності до спорідненої групи на рівень молочної продуктивності та параметри відтворювальної здатності корів джерсейської породи. Встановлено істотний рівень диференціації за основними господарськи корисними ознаками між групами напівсестер за батьком. Кращими кількісними показниками молочної продуктивності відзначилися дочки бугаїв DJ Jante 302761 ($P < 0,001$) та Headline 114114336 ($P < 0,001$), найгіршими – Karl 67037285. Найвищими показниками вмісту жиру і білка у молоці відзначилися дочки бугая Legal 61929249, найнижчими – Karl 67037285. Вплив походження корів за батьком на мінливість надою і виходу молочного жиру і білка становив 20,3–30,3 % (до $P < 0,001$), вмісту в молоці жиру та білка знижувався до 13,2–20,0 % ($P < 0,01$ і $P < 0,05$), а за ознаками відтворювальної здатності – до 7,8–19,0% за недостовірного рівня статистичної значущості. Препотентними за надоєм є бугаї Legal 61929249 і Headline 114114336, за вмістом і виходом молочного білка – Legal 61929249. Найвищим надоєм і виходом молочного жиру і білка як за першу, так і за кращу лактацію характеризуються корови спорідненої групи Observer 553236, найгіршим – спорідненої групи Surville 604694. Вплив належності до спорідненої групи на досліджувані ознаки виявився у разі нижчий (0,2–10,5 %) порівняно зі впливом походження за батьком. Зі зростанням надою корів за першу лактацію спостерігається стабільне та істотне зниження коефіцієнта відтворювальної здатності через подовження тривалості сервіс- і періоду між першим та другим отеленнями. Такий природний антагонізм не означає мети збільшення тривалості сервіс-періоду задля отримання максимальних надоїв первісток, оскільки це призведе до зменшення виходу телят і унеможливить своєчасний ремонт стада. Оптимальним вбачається роздоювання первісток до 8 тонн за 305 днів лактації зі збереженням задовільного рівня відтворення

Ключові слова: джерсейська худоба, бугай-плідник, коротка лінія, надій, відтворення, консолідованість



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Tuberculosis Pathology of *Fraxinus Excelsior* L. in Ukraine: Symptomatology, Etiology, Pathogenesis

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Abstract. Given the forestry, the ecological and economic value of forests with the participation of *Fraxinus excelsior* and taking into account the intensive deterioration of their phytosanitary status in modern conditions, a comprehensive study of symptoms, causes, and pathogenesis of ash tuberculosis with further development of effective protection measures, including using biological products based on *Bacillus sp.* and other myco- and microorganisms, is a particularly relevant area of research. The aim of the research is to identify negative abiotic and biotic factors in the pathology of *F. excelsior*. In the process of research general scientific and special research methods were used (microbiological, mycological, phytopathological, entomological, and silvicultural-ecological methods). It is emphasized that the pathology of the common ash is a multifaceted phenomenon with interrelated processes of infectious and non-infectious nature, which in recent years has led to epiphytic dieback and now has a tendency to increase. It has been established that tuberculosis of *F. excelsior* is the most common and harmful disease within the study region and causes more economic than environmental damage. Bacteria of the genera *Pseudomonas sp.*, *Erwinia sp.*, and *Xanthomonas sp.*, as well as micromycetes, which mainly take the place of the concomitant mycobiota. There are five stages (phases) of the development of tuberculosis pathology, which differ significantly in symptoms. The species composition of harmful insects has been identified. It is shown that hydrothermal stress is a catalyst for the epiphytic dieback of common ash. Direct dependence of the spread of tuberculosis on the share of ash in the stands of different age groups was revealed. In the study area, tuberculosis reaches epiphytotic on *F. excelsior*, especially at a young age. The expediency of distinguishing the causes and pathological processes associated with ash tuberculosis is indicated, so as not to confuse the disease-catalyzing factors and the factors that lead to the complete degradation of ash stands

Keywords: common ash, ash tuberculosis, antagonism, harmfulness of the disease, pathogen, symptomatology, pathogenesis



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INTRODUCTION

It is established that a peculiar trigger of the pathological process and genesis of the disease is a set of factors of synoptic nature and as a consequence of dysfunction of immune structures, with obvious manifestation and implementation of ecological and trophic niches of phytopathogens of fungal and bacterial etiology. According to the authors' research, the formation of neoplasms instead of ordinary inflorescences on common ash trees is associated exclusively with bacterial etiology, including the causative agent of ash tuberculosis – *Pseudomonas syringae* pv. *savastanoi*, and is one of the phases (stages) of pathogenesis [1; 2].

Phytoparasitic nematodes have a harmful effect on trees of the genus *Fraxinus*. Most often noted by researchers on *Fraxinus americana* – *Meloidogyne* sp., *Aphelenchoides* sp., *Criconema* sp., *Criconemoides* sp., *C. beljaevae*, *C. macrorodum*, *Ditylenchus* sp., *Gracilacus audriellus*, *Helicotylenchus* sp., *H. playturus*, *Hemicyclophora* sp., *H. gigas*, *Hoplolaimus* sp., *Longidorus* sp., *L. elongatus*, *Meloidogyne* sp., *M. ovalis*, sp': *Paratylenchus* sp., *Pratylenchus* sp., *P. crenatus*, *Rotylenchus* sp., *Trichodorus* sp., *T. aequalis*, *Tylenchorhynchus* sp., *Xiphinema* sp., *X. americanum*, *X. Chambersi*; on *Fraxinus excelsior* – *Helicotylenchus paxilli*, *H. varicaudatus*, *Pratylenchus penetrans*; on *Fraxinus mandschurica* – *Meloidogyne* sp.; on *Fraxinus nigra* – *Meloidogyne* sp.; on *Fraxinus pennsylvanica* – *Criconemoides curvatum*, *Xiphinema americanum*; on *Fraxinus syriaca* – *Meloidogyne javanica*; on *Fraxinus velutina* – *Meloidogyne* sp. Modern studies of the nematocomplex of ash trees indicate a particular danger from the species *Bursaphelenchus crenati* [3].

A special place in the pathological process of dieback of common ash should be given to phytoplasmas, as the least studied phytopathogens. Periodically in the scientific literature, there are reports of the viral origin of the pathogenesis of common ash. At the same time, today the world community knows only about the mosaic disease of trees of the genus *Fraxinus*, the causative agent of which is *Tobacco mosaic virus* (TMV). Thus, the pathology of *Fraxinus excelsior* L. is associated with various factors – micromycetes [4; 5], bacteria [6; 7], nematodes [3], mycoplasmas, harmful entomofauna [8], also with unfavorable climatic (synoptic) and soil-hydrological factors, this indicates that the pathology of *F. excelsior* is a multifaceted phenomenon in which the processes of an infectious and non-infectious nature are systemically interrelated, which significantly complicates the diagnosis of its root causes.

Now in Ukraine, there is a difficult situation with the phytosanitary state of common ash, which requires an urgent solution [1; 6]. A characteristic feature, in this case, is the consistent geographical deterioration of the state of tree stands subordinate to the State Forest Resources Agency of Ukraine, as well as ash trees in forest parks, field protection belts, in plantings of settlements. The visual manifestation of the consequences of pathology

is systemically interrelated with the hydrothermal indicators of the current year, the physiological state of trees, and the presence of phytophagous insects.

Of particular concern is ash tuberculosis (*pathogen Pseudomonas syringae* pv. *savastanoi*), which systemically affects trunks, shoots, and inflorescences [2; 7]. In particular, under the action of the pathogen, numerous wounds, voids, caverns, rotten areas, etc. are formed in the affected plants, not only impairing the physiological processes of trees and devaluing wood but significantly threatens the formation the seed of this valuable woody plant due to damage to the generative organs.

The purpose of this study is to identify negative abiotic and biotic factors in the pathology of *F. excelsior*, to determine the microbiota on infected shoots, leaves, and buds of dieback stands, to establish the dependence of the spread of tuberculosis on the proportion of ash in the composition of stands of different age groups.

THEORETICAL OVERVIEW

The implementation of their life strategies depends on competitiveness and aggression. Nematodes and mycoplasmas are also involved in the pathological process. It is important, according to the authors, that the possible mediating role of populations of arthropods, mainly xylophages, and their participation in the complex circulation process of pathogens are discussed in a certain way. Available primary sources do not make it possible to trace the process of transformation of populations of native pathogenic microbiota or attack of aggressive strains. It is important that in modern pathology of woody plants the problem of sanogenesis is practically not discussed. Recent reports of deteriorating deterioration of the sanitary condition and the dieback of *Fraxinus excelsior* in more than 30 European countries have spread and alarmed scientists and practitioners of the forestry industry, and have given rise to controversy over its causes.

The mass dieback of *Fraxinus excelsior* was first recorded in the early 1990s in northeastern Poland and Lithuania (according to the latest data, today the disease affects more than 30 thousand hectares or 60% of the entire area of ash stands) [9; 10]. The disease then spread north to Latvia and Estonia [11]. In 2002, this disease was first reported in Germany and Sweden (in 2010, common ash was included in the Red Book of Sweden) [12], in 2004 in the Czech Republic, Slovakia, Finland, and Denmark, and 2005 in Austria. Subsequently, in 2007, ash dieback spread to Hungary, Slovenia, and Norway. In 2008, the disease reached France, in 2009 – Italy and Greece, where it caused massive deaths of trees. Recent reports on the noted pathology of *F. excelsior* were received from Belgium, the Netherlands, England, and Ireland [13]. Ash trees are now dieback in 30 European countries. Programs of countries where signs of ash dieback have been identified, aimed at identifying the origin of the pathogen, assessing its impact on forests,

developing methods for diagnosing and conducting forestry in affected forests, including in the direction of the selection of ash for resistance to pathogens.

Now the degradation and mass dieback of ash stands has reached a global level and is noted practically throughout the range of many ash species, including *Fraxinus excelsior*. From different parts of the planet, there are reports of similar symptoms of pathology. Based on research, several possible reasons have been put forward.

In the etiology, the deterioration of the sanitary condition of trees of the genus *Fraxinus* prevails “mycological” point of view. In particular, the causative agent of “ash dieback”, which is considered the main pathology of ash, is called the anamorphic fungus *Chalara fraxinea* Kowalski. In 2009, it was discovered that this is the asexual stage of the teleomorphic species (new to Europe) *Hymenosyphus pseudoalbidus* Quel. [9]. Recently, the name of the fungus has been clarified *Hymenosyphus fraxineus* Baral et al. and genetic studies of the genomes of *H. pseudoalbidus* and *H. albidus* by molecular methods were carried out [5; 14]. It is worth noting that in the oak forests (fresh) of the Western Podillya of Ukraine the authors found identified typical symptoms of the disease known as “ash dieback” (“fatal disease” of ash, “peripheral death”, “pathogenic dieback of ash”) [15]. At the same time, from the pathology of the “ash dieback” type, identified several species of anamorphic fungi and bacteria, in particular *Pseudomonas syringae* pv. *savastanoi*, *Erwinia horticola* and *Xanthomonas* sp., however, *H. pseudoalbidus* was not isolated [7]. The role of basidiomycetes of the genus *Armillaria*, in particular *Armillaria cepistipes*, in the phenomenon dieback of an ash-trees with a root system is also known [4]. Of course, but not decisive, is the role of other species of fungal organisms, in particular *Alternaria* sp, *Epicoccum* sp, *Phytophthora* sp., in the dieback of trees of the genus *Fraxinus*.

Relatively small diversity of genera *Pseudomonas*, *Xanthomonas*, *Erwinia*, *Agrobacterium*, *Brenneria*, *Xylella*, *Rhizobium*, *Azotobacter*, *Corynebacterium*, *Bacillus*, *Clostridium*, *Enterobacter*, but a significant role in the pathological processes of forest woody plants, including, and common ash, have phytopathogenic bacteria. Among the infectious diseases of shoots, inflorescences and trunks of *Fraxinus excelsior*, the most common and most harmful is the disease of bacterial origin – tuberculosis, the causative agent of which is the phytopathogenic bacterium *Pseudomonas syringae* pv. *savastanoi* [16]. Scientists are constantly researching to better study the virulence and aggressiveness of the pathogen. Thus, in Italy, mutants of the bacteria *P. syringae* sp. *savastanoi* (for various manifestations of pathogenicity and hypersensitivity reactions) were isolated and characterized [11]. In Japan, *Pseudomonas syringae* strains are classified into five groups by comparing DNA homology. Currently, the aggressiveness of the pathogen is associated with the formation of phytohormones indole acetic acid and cytokinins. Studies of microbial-plant relationships are underway, in particular

in the induction of demutation processes in the phytocenosis and increase the immune protection of plants [17].

Invasive insect species, in particular *Agrilus planipennis* F., are dangerous for deciduous tree species, especially for common ash, because they are capable of attacking and leading to the rapid death of absolutely healthy trees [18].

Many authors argue that the cause of atypical clusters (galls, growths, neoplasms) is the insects *Eriophyes fraxinivorus* Felt (synonym for *Aceria fraxiniflora* Felt) [8; 19]. The authors analyzed the phytochemical composition of galls, which are formed on inflorescences of ash species (*Fraxinus angustifolia*, *F. excelsior*, *F. ornus*). However, it is not established and has not confirmed the causes of this phenomenon [18].

MATERIALS AND METHODS

Due to biological characteristics and wide ecological amplitude, in particular, significant shade tolerance in the first years of life, common ash acts as an integral component (as an accompanying woody plant) in many forest associations, while forming high-productive stands together with *Quercus robur* L., *Carpinus betulus* L., and other forest woody plants. At the same time, unique natural ash forests, which are mainly concentrated on rich loamy and viscous soils, have survived only in the Western Podillya of Ukraine, the climatic conditions of which are most favorable for the growth and development of this tree species.

The main algorithm for detecting and studying the pathology of *Fraxinus excelsior* included certain stages: exploration and forest pathological detailed examinations by general forestry and phytopathological methods; detailed examination and research of the affected organs, isolation of pathogens in pure cultures; verification of the properties of pathogens and their accurate identification; study of antagonistic relationships in the systems “bacterium-micromycetes” and “bacterium-bacterium”. The influence of meteorological factors as catalysts of the disease on *F. excelsior* and harmful insects has been studied, given the trophic links between insects (as vectors) and pathogens.

Reconnaissance and detailed forest pathological inspections of stands with the participation of *Fraxinus excelsior* were carried out with the establishment of 24 trial areas (2020-2021 years) in the state enterprises “Chortkivske forestry”, “Ternopil'ske forestry”, “Buchatske forestry” according to Standard of organization of Ukraine (SOU 02.02-37-476:2006). “Trial plots forest inventory. Method of conducting” (2007). 17 model trees were cut down. 240 samples were taken for myco- and microbiological studies; 110 isolates of micromycetes and bacteria were isolated, including 37 strains of phytopathogenic bacteria; the study of anatomical-morphological and physiological-biochemical characteristics of 120 strains of bacteria; 11 species of insects of harmful entomofauna were found. The density index for

each species of entomofauna is set between the percentage of populated trees and the average number of individuals per tree.

The number of microorganisms, depending on functional and other characteristics, was tested by their growth on special nutrient media (potato agar, meat peptone agar, meat peptone broth, malt extract of agar, Czapek medium, etc.). The pathogenic properties of the isolates were shown in laboratory and field conditions by artificial infection of vegetative and generative organs of *F. excelsior* and indicator plants (*Phaseolus vulgaris* L., *Nicotiana tabacum* L., *Kalanchoe laciniata* L.) bacterial suspension with a titer of 10^8 - 10^9 cells \times ml $^{-1}$ (according to the turbidity standard). Control – sterile tap water. The placement and size of bacterial cells, Gram staining, the morphology of colonies of microorganisms, their biological, biochemical, and cultural properties were studied using the different methods [20]. To determine the ability of bacterial isolates to ferment various sources of hydrocarbons, the mineral Omelyansky medium was used. Various organic compounds were used as sources of carbohydrates, in particular: lactose, xylose, rhamnose, trehalose, raffinose, L-arabinose, maltose, sorbitol, salicin, sucrose, galactose, fructose, glycerin, mannitol, citrate, etc.

The enzymatic or oxidative pathway of glucose assimilation was determined by the growth of microorganisms on Omelyanskiy's medium under anaerobic conditions under a 1 cm layer of vaseline oil. The indicator was an aqueous solution of bromothymol blue. Milk and gelatin were used to detect proteolytic enzymes in bacteria. The names of bacteria and micromycetes are given according to the atlases-determinants of bacteria and fungi and other specialized literature [20]. The species of phytophages were determined according to the "Atlas of insects of Ukraine", "Keys to the insects of the European USSR" and other determinants. Calculations and statistical data processing were carried out using *Microsoft Excel* computer programs.

RESULTS AND DISCUSSION

Forest pathological examination, symptoms and diagnosis of the disease

Ash tuberculosis is one of the most dangerous diseases of common ash, which in Ukraine has reached epiphytotic, especially on overgrowth origin trees. In modern scientific literature, this disease is associated with bacterial cancer of ash. Cancer, as one of the types of diseases, characterized by overgrowth of individual parts of the plant as a result of hyperplasia or hypertrophy, or both at the same time, which leads to the formation of tumors. Now, cancer is identified with ulcers of various shapes, highly healing or non-healing wounds, including non-infectious ("frosty cancer"), etc. *P. syringae* pv. *savastanoi* causes a typical tuberculosis disease, because tuberculosis is a tumor with voids or other defects, often filled with bacterial mucus, especially in the initial stages of pathology. These are the symptoms and inherent

in tuberculosis. In the literature, the symptoms of tuberculosis are described with the final manifestation of the pathological process. At the same time, certain symptomatic differences are inherent in various stage of the manifestation of the disease, which made it possible, with certain conventions, to distinguish several stages (phases) of pathology. According to the authors, this makes it possible to diagnose the affected tree in time at any stages of the disease, with the subsequent development of appropriate protective measures.

The infection of common ash begins at the age of 2-3 years at the corresponding height of the trunk. Infection can be both exogenous and endogenous. The primary symptoms of tuberculosis (the so-called "scab") appear on young trunks with a smooth (primary) grayish-green bark and are characterized by slight local swelling of the upper layer of cells, the appearance of microcracks, and small elliptical soft tumors filled with an odorless gray sticky bacterial mass.

A narrow, shallow, oblong, straight, or tortuous crack forms in the center of the bulge. Exudate, released through cracks, upon drying forms a thick or thin gray membrane, which remains on the surface of the periderm for a long time. The rhytidoma of the affected trees in the places of the pathological process becomes dark gray, gradually dies off in small pieces, and disappears. Along the perimeter of the lesion, the bast part of the trunk turns slightly yellow or reddens. On a cut of the primary bark, a narrow, colored, winding strip is always visible. Over time, the affected primary bark dries up, hardens, and cracks, but the wood is usually not exposed. The site of the lesion seems to be overgrown, but complete overgrowth does not occur. Therefore, local necrosis sinks into the trunk, which leads to the formation of black, dark brown stripes of various thickness in it, large or smaller voids, rotten areas, in the spring-summer period are sometimes filled with a sticky bacterial exudate. Over time, under the influence of factors favorable for the pathogen, new lesions are formed (the so-called "spread" of the disease) along the length and perimeter of the *F. excelsior* trunk. New foci of tuberculosis can appear in different places of the tree without a certain relationship and sequence (Fig. 1a).

In "real tuberculosis", typical tuberculosis formations are formed with a subsequent increase in their size both along the length and along the perimeter of the trunk. Under the influence of the pathogen, a certain deformation of it occurs in the trunk. Necrosis at the initial stage of the disease, especially on young ash trees and shoots, small, ranging in size from 1 to 2-3 cm, but grow over time, often merge, forming a straight or winding strip of dead sapwood, time up to 0.5 m and more. The depth of placement of various flaws in the wood usually depends on the period of infection of the tree: the earlier the tree is infected, the deeper the wounds are formed in the trunk. As the tree grows, the number of defects increases in proportion to new lesions (Fig. 1b).

In addition to the trunks and branches, the causative agent of tuberculosis also affects the inflorescences of common ash, which can potentially threaten the seed recovery of this valuable woody plant (“deformation of the generative organs”). Flowers affected by the causative agent of tuberculosis usually do not form single

ash-keys, but accumulate around the undeveloped apical bud and form small (1-2 mm in diameter), first light pink, purple, and then dark brown tuberculous accumulation of rather large sizes (sometimes up to 10 cm), resembling bunches of grapes and remain on the tree until spring (summer) the next year (Fig. 1c).

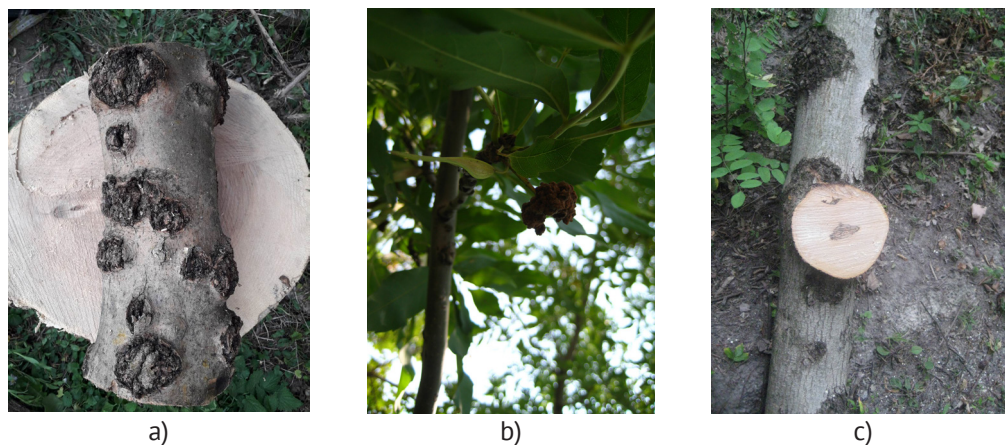


Figure 1. Stages of tuberculosis *F. excelsior*: a – “actual tuberculosis”, b – “deformation of generative organs”, c – “wood defects”

Based on the analysis of the phytochemical composition of galls that form on the inflorescences of European ash species (*F. angustifolia*, *F. excelsior*, and *F. ornus*), it is argued that the cause of their occurrence is the insects *Eriophyes fraxinivorus* Felt (synonym for *Aceria fraxiniflora* Felt) [8], however, so far such statements have not been properly confirmed [18]. Galls, instead of the usual inflorescences on common ash trees, have a bacterial etiology associated with *Pseudomonas syringae* pv. *savastanoi* – the causative agent of ash tuberculosis [7]. In particular, the authors found inflorescences affected by the causative agent of tuberculosis both on trees with tuberculous pathology and on externally healthy ones, which indirectly testifies to *Ps. syringae* pv. *savastanoi* as a vital obligate. The number of lesions on a tree depends on the degree of damage and the age of the tree, but mainly on one affected tree, dozens and even hundreds of foci of tuberculosis can be counted. In this case, up to 60 or more lesions can form on one running meter

of the trunk. Trunks on which single tuberculous lesions are formed are rare. That is, if a tree is infected with a bacteriosis causative agent, then the disease progresses rapidly, often affecting the entire trunk and branches. Ash tuberculosis is a chronic disease.

In an infected tree, wounds form across the entire thickness of the trunk at different heights. Sometimes there is a rupture of annual rings under the influence of myco- and microbiota, necrotic areas spread through several annual rings. If there are voids in the longitudinal and transverse sections, it is possible to establish at what age the tree was infected in a given section of the trunk (Fig. 1). The causative agents of common or graded cancers, mainly *Nectria galligena* Bres, are usually involved in the formation of open ulcers, or *Endoxylina stellulata* Rom. (anamorph *Libertella fraxini* Ogan.). And then the disease proceeds with symptoms characteristic of these pathogens (ulcers are formed) (Fig. 2).



Figure 2. Change of typical color and formation of open wounds (ulcers)

Rotten areas on the ash tree trunk are formed exclusively with mixed infection with the formation of open ulcers with the participation of wood-destroying and wood-coloring fungi, in particular *Ascomycota*, *Basidiomycota* and *Deuteromycota*.

Tuberculosis causes more economic damage than environmental damage. Affected trees of older age groups die off relatively rarely, but as a result of a characteristic pathological process, wood is devalued. Affected trunks are usually retracted into firewood. The most affected by the causative agent of tuberculosis are sprouting ash trees. Taking into account the biology of the pathogen and the pathogenesis of the disease, ash trees, which at a young age have at least a single, insignificant damage to the trunks or branches, should be cut down and disposed of, since under the conditions of Ukraine, against the currently existing infectious background, to grow ash trees with high quality wood age ripeness is problematic, and partly impossible (for the reasons noted above).

Alone on ash trees in the fresh oak forests of Western Podillya of Ukraine “ash dieback” was found, which is considered the main pathology of ash in Eastern Europe. Symptoms of the disease appear at any age of the plant, but young plants of *Fraxinus excelsior* are especially sensitive to damage. In affected plants, there is a gradual (sometimes sudden) dying off of young plants or individual shoots of the crown due to the formation of local necrotic areas on the shoot (trunk). The leaves above the lesion site wither (starting from the top), and by the end of summer they turn black (like those burnt by fire) and do not fall off for a long time.

Etiology and the dynamics of the development artificial infection of the organs of Fraxinus excelsior

Anatomical, morphological, cultural, and physiological-biochemical studies carried out in the Department of Phytopathogenic Bacteria D.K. Zabolotny Institute of Microbiology and Virology of the National Academy of

Sciences of Ukraine made it possible to establish that the microbiota of tuberculous pathology of *F. excelsior* is made up of bacteria of the genera *Pseudomonas*, *Erwinia*, *Xanthomonas*, in particular *Pseudomonas* sp., *P. syringae* pv. *savastanoi*, *P. fluorescens*, *P. syringae*, *P. agglomerans* (synonyms *Enterobacter herbicola*, *E. agglomerans*, *Erwinia herbicola*), *E. horticola*, *Xanthomonas* sp., as well as the spore-bearing bacteria *Bacillus* sp., which accompanied the tuberculous pathology of *F. excelsior* at all its stages. The average values of the content of bacteria isolated from the vegetative and generative organs of *F. excelsior* ranged from 1 to 168 colony-forming units (CFU). The largest number (116, 168 CFU) of bacteria was obtained during the isolation of *Ps. syringae* pv. *savastanoi*. At the same time, for bacteria, primarily phytopathogenic, it is not so much their quantity that is important as their presence. Under favorable conditions for phytopathogenic bacteria, they can very quickly fill an ecological niche to a threshold concentration, thereby causing even epiphytotic, to a certain extent, which is observed during the mass drying of many species of both coniferous and deciduous woody plants [7].

The only reliable way to separate pathogens from saprotrophs is pathogenicity, that is, the ability of a microorganism to infect living cells. In vivo testing of the pathogenicity of the isolates isolated from the tuberculosis pathology of ash was carried out by injecting a suspension of a daily culture of microorganisms ($8.6-9.97 \text{ CFU} \times \text{ml}^{-1}$) into the trunks and by introducing a pure bacterial culture under the bark ($14.1-21, 27 \text{ CFU} \times \text{ml}^{-1}$) and a mixture of the “Victant” preparation based on *Bacillus* sp. with a collection strain *Pseudomonas syringae* pv. *savastanoi* working solution with a titer of $1 \times 10^7 \text{ CFU} \times \text{ml}^{-1}$ (Fig. 3) into mechanical damage to the section of the trunk (cut) of a bacterial loop previously sterilized over the flame of an alcohol lamp. Control – sterile tap water. When carrying out the above studies, the circadian rhythms of plant resistance to bacteriosis pathogens were taken into account.

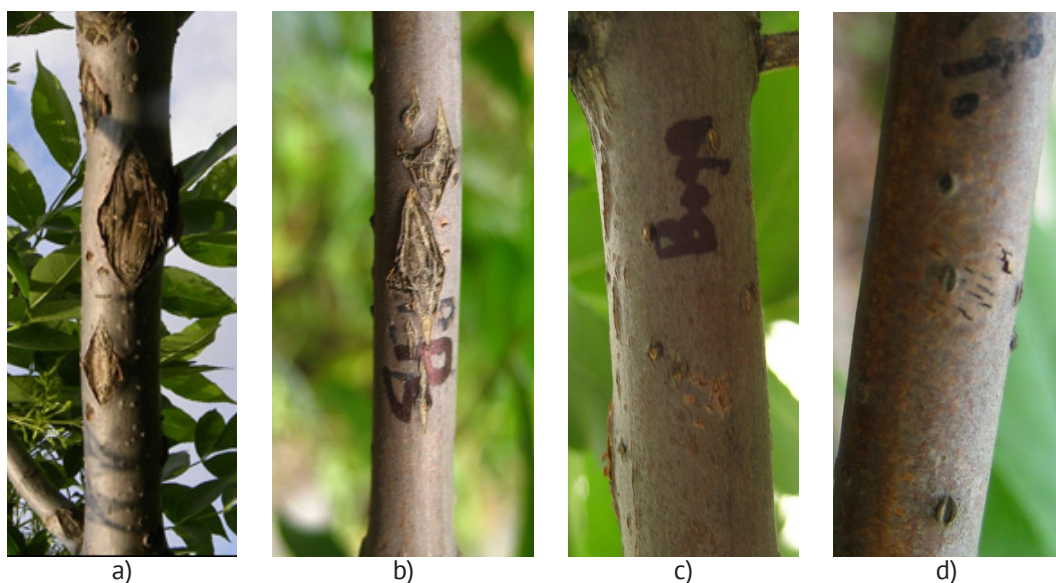


Figure 3. Natural tuberculosis lesions (a), artificial lesions of common ash shoots

by the *Pseudomonas syringae* pv. *savastanoi* (strain Ps) (b), control (c) and a mixture of Victant-strain Ps (d)
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Establishing the true causative agent of the disease is significantly complicated by the wide systemic interaction of microorganisms with all living components of the biogeocenosis against the background of constant changes in environmental conditions, ecological plasticity, and variability of phytopathogenic bacteria. Observation of the course of tuberculous pathology with artificial lesions of *Ps. syringae* pv. *savastanoi* continued for a year from the moment of infection, constantly noting the dynamics and progress of this phenomenon. The dynamics of the development of artificial infection of the branches of *Fraxinus excelsior* shows that the first signs of damage manifested themselves in the cracking of the bark at the injection site of the bacterial suspension already on the 15th day of the experiment.

After 10 days, individual cracks merged into one continuous wound, its size increased, and the destruction of not only the surface bark but also the primary bark and bast became noticeable. Three months after the lesion, the upper layer of the bark separated, there was “exposure” of the integumentary tissues and scarring of individual layers. The process of development of the affected area began to fade, but in the spring of the next year (9 months after the defeat) the process of the development of the disease resumed, it acquired a form typical for tuberculosis. Internal cracks deepened and increased in size. A year later, symptoms of tuberculosis clearly appeared in the affected areas.

An interesting fact is that from the affected *Ps. syringae* pv. *savastanoi* of common ash trees isolated *Xanthomonas* sp. (Strain K₃), which revealed pathogenic properties in the experiment. Now in the literature, these bacteria are not marked as pathogens for *F. excelsior* (there is only information about *X. juglandis* as the causative agent of bacteriosis *Juglans regia* L. At the same time, the sensitivity of *F. excelsior* to *Xanthomonas* sp. in case of artificial infection, it testifies, on the one hand, to the expansion of specialization, and on the other, to the insufficient study of the bacterial pathology of forest woody plants. Now *Xanthomonas* sp. isolated from many agricultural plants, where it causes numerous types of diseases – from necrosis to burns [20].

In general, the expected susceptibility of ash to *Erwinia horticola* (strain K₂), which was isolated from the bark of tuberculosis-affected trees. This bacterial species was first isolated from *Fagus sylvatica* in 1972, where it caused a rather harmful disease known as black bacteriosis in woody plants. Note that this disease resembles the “fatal disease” of ash in symptoms (now this disease, as have already noted, is associated with micromycetes,

in particular with *Chalara fraxinea*). In the course of analysis of the mycobiota of common ash branches affected by tuberculosis pathology in the entire research region (including identified only to the level of the genus *Fusarium* sp. and *Phoma* sp.), 7 genera and 10 species of micromycetes were isolated, in particular, at different stages of tuberculous pathology *Fraxinus excelsior*, isolated *Acremonium strictum*, *Cladosporium cladosporioides*, *Cylindrocarpon didymum*, *Fusarium* sp., *F. sporotrichiella*, *F. heterosporum*, *Phoma* sp., *Ulocladium botrytis*, etc. Usually, samples of the affected tissues had a mixed infection, which consider which part of the concomitant mycobiota, however, as the cause of the mass dieback of ash trees in the study region.

The authors isolated anamorphic micromycetes, in particular, *Fusarium* sp. and bacteria *Pseudomonas syringae* pv. *savastanoi*, *Erwinia horticola* and *Xanthomonas* sp. Artificial infection of the ash organs with micromycetes did not lead to symptoms similar to “ash dieback”, and infection with *P. syringae* pv. *savastanoi* caused pathological processes similar to tuberculosis. In other words, all currently known pathogens of necrotic diseases of forest woody plants are directly involved and accelerate the death of woody plants and organs, in particular shoots, at later stages of pathology and are usually secondary, although no less harmful factors.

Studies have established a direct relationship between

Pathogenesis (spread of tuberculous pathology in stands of different ages, tree species composition and origin)

the prevalence of *Fraxinus excelsior* tuberculosis and its share in stands of various age groups. With a decrease in the proportion of ash in the stand, a decrease in the number of infected trees by *Pseudomonas syringae* pv. *savastanoi*. Thus, in ash stands the prevalence of tuberculosis was the highest for all age groups: young – 79.3%, middle-aged – 47.8%, pre-mature stands – 42.3%. In young, middle-aged, and mature stands with 6–9 units of *Fraxinus excelsior* in the composition, the prevalence of the disease was 41.6%, 33.6%, and 30.7%, which is 1.4–2 times less than in “net” stands. With the share of ash in the stands within 3–5 units, the prevalence of the disease in young, middle-aged and mature stands was 24.2%, 20.5% and 15.8%, respectively.

At the same time, 17.6% were found in stands with a share of *F. excelsior* in the composition of young, middle-aged, and pre-mature stands; 14.8% and 9.7% of trees affected by the tuberculosis pathogen, respectively, which is 4.5; 3.2 and 4.3 times less than in “net” stands of the respective age groups (Fig. 4).

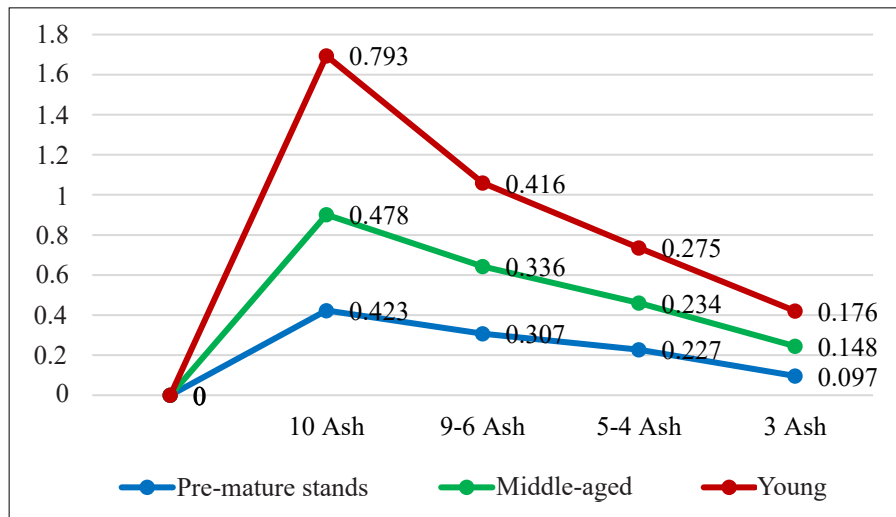


Figure 4. Distribution of tuberculosis in stands of different ages depending on the share of *Fraxinus excelsior* in the stand

The obtained data indicate that the share of common ash in stands within the coenotic optimum (25-30%) during the whole period of stand cultivation is one of the important factors of induction of demutation processes in forest biocenoses and promotes the formation of highly productive, biologically resistant oak-ash stands from the point of view of activation of metabolic processes, and

increase of resistance to pathogens of infectious diseases, in particular to ash tuberculosis. As for the decrease in the prevalence of the disease in the stands of older age groups (middle-aged, pre-mature) compared to the young, it is usually directly related to economic activity. In addition, a certain number of affected trees (in young – more, in the middle and middle-aged – less) dies naturally (Fig. 5).



Figure 5. The spread of tuberculous pathology of ash, depending on the degree of density (a), age (b), composition (c) and origin (d)

Sprouting ash stands are characterized by reduced resistance to the pathogen of tuberculosis. Both in the study region and in the *F. excelsior* range in general, including in Ukraine, tuberculosis has reached epiphytosis on overgrown plants, especially at a young age (with

a significant spread and development of tuberculosis, such plants usually die). Given the pathogenesis of *Pseudomonas syringae* pv. *savastanoi* have identified three categories of lesions of the trunk: continuous, local, and single (focal or spotted) (Fig. 6).

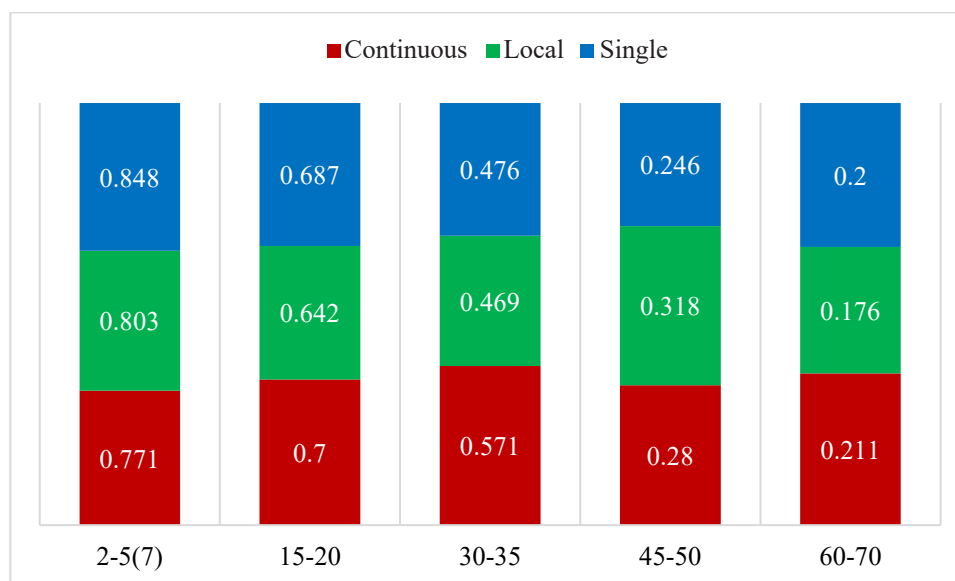


Figure 6. Distribution of tuberculosis *Fraxinus excelsior* in sprouting stands

A decrease in the number of affected *Fraxinus excelsior* trees with age (in 2-5 (7)-year stands 80.7% of tuberculosis-infected plants were found, in 15-20-year-olds 67.6%, in 30-35-year stands 50.5%, at the age of 45-50 – 28.1%, at the age of 60-70 – within 20%) associate with the above factors. However, it is not about the attenuation of the pathological process with age (because the affected *Pseudomonas syringae* pv. *savastanoi* plant does not free itself from infection), but about the death (albeit insignificant) of individual specimens and the removal of diseased trees during cleaning cutting. It should be noted that the affected plants at any age have hidden defectives in the wood (blackening, cracks, rotten areas with a significant spread along the trunk), which devalues it.

Meteorological factors can be catalysts for pathology in stands involving *Fraxinus excelsior*. Based on the calculation of the moisture supply coefficient, have established certain dependencies in the prevalence of tuberculosis on air temperature and precipitation.

Phytophagous insects in the circulation of phytopathogens *Fraxinus excelsior* L.

In the study area, found 11 species of phytophagous insects of the series *Coleoptera*, *Hemiptera*, *Homoptera*, *Diptera*, and *Lepidoptera*, which are directly or indirectly ecologically and trophically related to the vegetative and reproductive organs of *Fraxinus excelsior*. In particular, *Lignyodes enucleator* Panz. and *Dasyneura fraxini* Kjeff. were identified on the generative organs of common ash. The density of the settlement is in the range of 15-20%. The activity of *Erannis defoliaria* Cl., *Phytomyza heringi* Hend., *Prociophilus nidificus* Loew., *Psyllopsis fraxini* L., *Prays curtisellus* Don. was noted on the leaves and buds. The density of the colonization is in the range of 5-30%.

Prays curtisellus Don., *Fonscolombea fraxini* Kalt., *Nylesinus crenatus* Fabr., *Hylesinus fraxini* Ranz., *Zeuzera*

pyrina L. were found on the branches and trunks. The density of the colonization is in the range of 15-30%. Their pronounced negative impact on producers is usually manifested as a result of stressors. These are, first of all, synoptic anomalies, as well as various anthropogenic factors associated with economic activity.

Analytical analysis of the relationship between dominant species of phytophagous insects, trophically related to the vegetative and generative organs of *Fraxinus excelsior*, indicates the existence of possible ecological and trophic links between carpophagous insects (including *Lignyodes enucleator*) and pathogens of ash tuberculosis as a component. Further research was aimed at a partial experimental substantiation of this phenomenon.

The essence of scientific assumption was based on a detailed analytical foundation of existing literature and own research. Life strategy, biology and ecology *L. enucleator* are completely transformed into a complex biocoenotic structure of deciduous woody plants. A characteristic feature of the species is the lack of cyclical seasonal development. Its number is fully correlated with the dynamics of seed production *Fraxinus excelsior*. Purely formally, the species does not belong to phytophages. Adults and larvae do not cause defoliation, which is why *F. excelsior* and *L. enucleator* trees are not in antagonistic relations.

Imago *Lignyodes enucleator* appears in late May. Initially fed on buds and leaves, during additional feeding damage the young seeds of *Fraxinus excelsior*, laying the ovipositor in it. This period, according to the authors, is considered critical in the genesis of *F. excelsior* and interaction with the pathogen (in particular with the causative agent of tuberculosis). It is at this time that the primary damage to the trees occurs. This is the primary gateway to infection.

The larvae feed on seeds until autumn, in September-October they gnaw small holes in the shell and

migrate into the soil for the winter, where they hatch in the spring. The critical period of their development is long (8-9 months – the period of wintering and diapause). As a result, during the spring reactivation their mortality rate did not exceed 32-40%. Viability was largely ensured by such a characteristic feature of the species as the preparation of a specific ecological niche – an area of soil saturated with a special organic secretion that protects against various stressors (entomopathogens and entomophages) – for overwintering phytophages.

It is likely that the primary lesion of *Pseudomonas syringae* pv. *savastanoi* occurs with the participation of *Lignyodes enucleator* populations. Moreover, there is every reason to assume, which is confirmed experimentally,

that the causative agent of tuberculosis is transmitted not only by inoculation, but also transovarially. This means that the ovipositor of *L. enucleator* retain the pathogen and that they are the cause of the primary damage to trees.

It should be noted that from the galls left on ash-keys due to damage to their *Lignyodes enucleator*, were isolated bacteria that in the experiment showed pathogenic properties on both *F. excelsior* and indicator plants. Further studies of anatomical-morphological and physiological-biochemical properties of isolates allowed to classify them as gray- and yellow-pigmented species of bacteria, in particular *Xanthomonas* sp. and *Pseudomonas* sp. (Fig. 7).

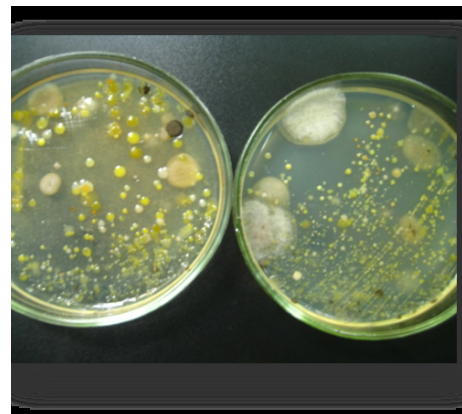


Figure 7. Galls on the ash-key (left) and bacterial colonies isolated from them (right)

Therefore, the probability of insect transmission of the bacteriosis pathogen by insects is quite significant. It grows during the ovipositor-period of females *Lignyodes enucleator* in ash-key of *Fraxinus excelsior*. It should also be emphasized that bacterial phytopathogens do not exhibit entomocidal properties in relation to *L. enucleator* and other insects. This property was first experimentally substantiated by us. Of course, further special in-depth studies are needed to determine the role and significance of phytophagous insects in the preservation and circulation of the pathogen inoculum in ecosystems.

Thus, studies make it possible to come to conclude non-obvious ecological, trophic, and mechanical links between the causative agents of tuberculosis *Fraxinus excelsior*, and phytophages with a specific trophic specialization, in particular from carpophagus, in the accumulation, preservation and transmission of the inoculum *Pseudomonas syringae* pv. *savastanoi* in natural ecosystems.

CONCLUSIONS

The current phytosanitary condition of *Fraxinus excelsior* in the forests of Ukraine is associated with a complex of adverse abiotic and biotic factors in their systemic interaction. Symptoms and features of the pathogenesis of tuberculosis *Fraxinus excelsior* have been studied. There are five stages (phases) of the disease and three

categories of trunk damage, which allows you to identify the affected tree in time for each age group.

The microbiota of infected shoots, leaves, and buds of dieback stands of *Fraxinus excelsior* is represented by a complex of pathogenic species of the genera *Pseudomonas* sp., *Erwinia* sp., *Xanthomonas* sp., which are dispersedly localized in the affected area. The most widespread and harmful component of pathogenic microflora is the causative agent of tuberculosis *F. excelsior*, which identified as *Pseudomonas syringae* pv. *savastanoi*. During artificial infection, determined that *P. syringae* pv. *savastanoi* showed high pathogenic properties on various organs of *F. excelsior* and indicator plants (*Phaseolus vulgaris*, *Nicotiana tabacum*, *Kalanchoe laciniata*). *F. excelsior* leaves are not sensitive to the pathogen. From the lesions of *Fraxinus excelsior*, 10 species of micromycetes belonging to anamorphic fungi were isolated. *Ulocladium botrytis* is characterized by a high colonization rate (57.1%), while *Acremonium strictum*, *Cylindrocarpon didymum*, *Fusarium sporotrichiella*, and *F. heterosporum* are characterized by a low one (14.3%).

11 species of phytophagous insects (*Coleoptera*, *Hemiptera*, *Diptera*, *Lepidoptera*) were identified and their ecological and trophic relationships with phytopathogenic bacteria in the accumulation, preservation and transmission of the inoculum *Pseudomonas syringae* pv. *savastanoi* in forest biocenoses. The direct dependence

of the spread of tuberculosis on the proportion of ash in the composition of stands of different age groups was revealed. In the study region, tuberculosis reaches epiphytotic on the ground-ash trees, especially when young.

For the purpose of prevention and to reduce the general infectious background, systematic monitoring should be carried out in stands with the participation of *Fraxinus excelsior*, to observe the cenotic optimum of ash in the composition of forest stands, to prevent thickening, to remove and dispose of young ground-ash tree affected by *Ps. syringae* pv. *savastanoi*, and create favorable conditions for the growth and development of common ash. The use of biological products based on

Bacillus sp. and other myco- and microorganisms with existing antagonistic properties to phytopathogens.

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Туберкульозна патологія *Fraxinus Excelsior* L. в Україні: симптоматика, етіологія, патогенез

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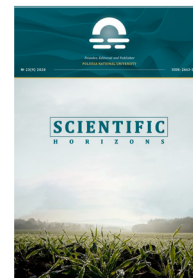
Анотація. Зважаючи на лісівничу, екологічну та господарську цінність деревостанів за участю *Fraxinus excelsior* та враховуючи інтенсивне погіршення їх фітосанітарного стану останніми роками, комплексне дослідження симптоматики, етіології та патогенезу туберкульозу ясен з подальшою розробкою ефективних заходів захисту, зокрема із використанням біопрепаратів на базі *Bacillus sp.* та інших міко- і мікроорганізмів, є наразі особливо актуальним напрямком досліджень. Мета роботи полягає у виявленні негативних абіотичних й біотичних, зокрема паразитарних, чинників у туберкульозній патології *F. excelsior*. У ході виконання дослідження були використані загальнонаукові та спеціальні (мікробіологічні, мікологічні, фітопатологічні, ентомологічні та лісівничо-екологічні) методи дослідження. Акцентується увага на тому, що патологія ясен звичайного – явище багатогранне зі взаємопов'язаними процесами інфекційного та неінфекційного характеру, яке в останні роки призвело до епіфітотійного всихання і наразі має тенденцію до зростання. Встановлено, що туберкульоз ясен звичайного є найбільш поширеним і шкочинним захворюванням у межах регіону дослідження і завдає здебільшого економічних, ніж екологічних збитків. З туберкульозної патології ізольовані бактерії родів *Pseudomonas sp.*, *Erwinia sp.* та *Xanthomonas sp.*, а також мікроміцети, які, головним чином, займають місце супутньої мікобіоти. Виділено п'ять етапів (фаз) розвитку туберкульозної патології, які суттєво різняться за симптоматикою. Ідентифіковано видовий склад шкочинної ентомофауни. Показано, що гідротермічний стрес є каталізуючим чинником епіфітотійного всихання ясен звичайного. Виявлена пряма залежність поширення туберкульозу від частки ясен у складі насаджень різних вікових груп. У регіоні досліджень туберкульоз досягає епіфітотії на паростевих деревах *Fraxinus excelsior*, особливо молодого віку. Вказується на доцільність розмежування причин і патологічних процесів пов'язаних із туберкульозом ясен, щоб не змішувати каталізуючі хворобу фактори і фактори, які призводять до повної деградації ясеневих деревостанів

Ключові слова: ясен звичайний, туберкульоз ясен, антагонізм, шкочинність захворювання, збудник, симптоматика, патогенез

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Inventory Management at the Enterprise in the Field of Probability Models

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Abstract. The inventory management system is designed to continuously ensure the production activities of the enterprise with all necessary resources. The purpose of this study is to build a probabilistic model that can be proposed as a new inventory model, which establishes the relationship of period factors between the purchase of parts and the duration of their suitability, which affect inventory management. The research methods are based on a probabilistic approach using continuous distributions. Using the statistical method, point estimates were found for the studied parameters: mean and standard deviation. The histograms of relative frequencies between dates of two next purchases, volume of purchases of details and days of replacement of the fulfilled details are constructed. The critical areas for the studied parameters are illustrated. The values of the difference in days between the purchases of parts and the values of purchases of parts that meet the normal distribution of random variables with the appropriate parameters, as well as the critical values of the need for parts in the production process. The size of the part reserve, which corresponds to Erlang distribution, was found, depending on the established risk factor. For different values of this factor, the value of the difference in days between the purchases of parts, the size of purchases and the reserve of parts that correspond to the distributions of random variables, as well as the critical value of the need for parts in the production process to avoid downtime. Using the central limit theorem, it is shown that the purchase volume of parts and the volume of used parts are distributed according to the normal law. The study concludes that the probabilistic approach is the basis for forecasting inventory management in the enterprise, taking into account the risks associated with determining the optimal demand for raw materials in the enterprise

Keywords: stocks, costs, reserve, normal distribution, Erlang distribution



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INTRODUCTION

One of the main tasks in market conditions is to increase the efficiency of the enterprise by optimizing the use of its resources, building a promising production program. The use of models allows to solve the issues of forming the optimal production program of the enterprise, investing in production, and also helps to carry out strategic planning of enterprise development. The successful development of the enterprise will largely depend not only on the marketing strategy, but also on the purchase of the products it needs [1; 2].

The problem of inventory management today is relevant for enterprises, which is caused by the following reasons: inconsistency in the rhythm and continuity of production, as well as the rhythm of production of the supplier and consumer; discreteness of the supply process; random fluctuations in consumption intensity and different duration of intervals between deliveries relative to the design level. This leads to the creation and storage of production or inventories, which may consist of raw materials, semi-finished products, components, goods, waste, etc. In addition, capital can also be considered as a stock, the cost of storage of which is determined by inflation [3; 4].

When managing production or inventories, there are two main questions: when to replenish the stock and what should be its optimal size. Obviously, stocks require certain costs for their storage until they are sold. Moreover, due to the share of working capital that is invested in stocks, the company's losses increase. Therefore, in each case, it is important to find the optimal cost-benefit ratio of the selected level of stocks and determine which stocks are sufficient for each group of goods or raw materials. To do this, build a mathematical model that describes such a system. The value of inventory management models lies in their accuracy, which allows not only to reduce operating costs, but also the cost of stockpiling.

There are different ways to manage inventory with different business models of inventory management, as well as types of goods and services. Each company has a unique location, infrastructure and logistics. Therefore, you need to find mechanisms that meet the requirements of the enterprise, to choose special models of inventory management to coordinate business processes. Assume that there are expected annual raw material costs of an enterprise. During the year, raw materials are replenished n times in equal batches. Since the consumption of raw materials is a random variable, in order to have enough raw materials for each of the n time intervals, you need to create a certain additional stock, which is called a reserve stock. In this case, the company creates a reserve in a predetermined amount, and then makes regular purchases of raw materials. Thus, when the main stock is depleted, and the company did not have time to purchase a new batch of raw materials, unforeseen needs are covered from the reserve. Therefore, the main task is

to determine the optimal size of the reserve. After all, it is clear that if the company creates a large reserve, it will cover all possible unforeseen costs of raw materials, but in this case, the cost of storing such a reserve will be quite large.

In practice, the calculations of the optimal size of the reserve stock are based on some, pre-established, probability that the demand for raw materials for a given period of time will not exceed the existing reserve. This probability is called the reliability factor. The risk factor is also defined as the probability that the reserve will be insufficient. If for some reason such a risk factor is set, then on the basis of statistics you can simulate this situation and determine the optimal size of the reserve. A natural question arises: what should be the risk and, accordingly, the reserve, so that the cost of its storage or possible shortage was minimal.

In the last few decades, interest in procurement and inventory theory has not diminished [5-7]. And despite the fact that scientists have developed many methods of inventory management and solved a large number of related practical problems, but the question of applying probabilistic models in conditions of uncertainty in inventory management in the enterprise is still relevant.

The purpose of this study is to find the optimal reserve stock, when the size of raw material needs is distributed at different time intervals and by different distributions.

The realization of this goal is achieved by solving the following tasks: accounting for the current level of stock in warehouses of different levels; determining the size of the order; determining the interval between orders.

The materials of the study will be useful for further study of the specifics of inventory management systems and can be used in planning production costs.

LITERATURE REVIEW

To minimize the costs associated with the acquisition and storage of stocks, determine the optimal size of the order to replenish stocks and the time of submission of the order to replenish stocks [8]. These problems are solved with the help of automated inventory management systems and with the use of economic and mathematical methods [9]. A large number of monographs are devoted to this topic, among which it is possible to note [10-12]. Here are some works that are devoted to the tasks of inventory management, related to the use of mathematical modeling.

In [13] calculated the efficiency of the use of inventory, which helps to minimize the cost of transportation and storage of products. The author in [14] on the example of a study of the company with two indications that inventory management should take measures to implement a strategy of inventory control to optimize the production process, inventory costs and thus increase efficiency. In [15] considered the problem of inventory

management based on the model of mathematical programming. J. Madhuri [16] investigated how the introduction of neural networks can improve profitability by reducing capital for inventory, forecast orders and calculate the stock of products accordingly. In [17], a new business model was proposed for a multi-stage supply chain inventory management scheme. The aim was to investigate the potential reduction of the overall costs of the enterprise and, conversely, whether such an approach can significantly improve the level of service achievable through more efficient resource management.

In [18] five models for the problem of the number of economic orders are considered. These models are nonlinear functions with binary variables that are related to the procurement strategy and are also responsible for accepting or rejecting each strategy.

There is a number of scientific studies in the development of various models of inventory management, as well as their evaluation. All models are divided into two main types:

- Deterministic models (built on the assumption of the absence of uncertainty associated with demand and replenishment [19]).

- Probabilistic models (take into account the fact that there is always a certain degree of uncertainty associated with the structure of demand and the time of execution of stocks [20]).

Here are three of the most popular deterministic models of inventory management:

1. Economic order quantity (*EOQ*). This inventory model requires constant checking of inventory levels and is reduced to the formula $EOQ=2 \cdot D \cdot S / C$, where D is the annual demand, C is the cost of delivery, S is the cost of the order. The *EOQ* model expects a consistent product request and offers the availability of items to be replenished [21-24].

2. Economic purchase quantity (*EOQ*). The model complements the *EOQ* and allows you to calculate the volume of inventory production. Inventories can be managed using the inventory turnover ratio, which establishes the relationship between average inventories and the value of inventories consumed or sold over a period of time [25].

3. ABC analysis. Often used with other inventory management models, such as Just in Time (JIT). Inventories are sorted by groups A, B, or C to determine the most stringent control requirements with the greatest degree of attention for the contribution of the inventory management model to the object of most interest. Thus, the company applies a selective approach to controlling investments in various types of stocks [26].

Deterministic calculation methods are used in the calculation of secondary demand for materials according to the known primary [27]. In the analytical method, the calculation is based on the product specification [28]. The synthetic method involves calculations for each group of parts based on the degree of their applicability at individual levels of the hierarchy [29-31].

The probabilistic model is based on the assumption that there is some uncertainty associated with demand. In this model, demand may fluctuate and may not always be predictable. The probabilistic approach allows to change demand and it is considered at stock management [32; 33].

Stochastic calculation methods allow to establish the expected need on the basis of numerical data that characterize its changes over a period of time [34]. For this purpose, the approximation of average values is used (used in conditions when the demand for materials varies by months at a stable average value), the method of smoothing (the coefficient that is selected to minimize the forecast error is calculated) and regression analysis (involves the approximation of known trends in the consumption of material resources using mathematical functions that can be extrapolated to the future) [35; 36].

Note that the warranty stock of raw materials at the enterprise is intended for use when [37]:

- demand exceeds the forecast;
- the relevant material is produced less than planned;
- the actual execution time of this order exceeds the usual term.

In [38], the optimal size of the reserve stock was found, which corresponds to the risk factor at which the costs associated with storage and scarcity are minimal. It should be noted that found in this work, such a coefficient in practice can be quite large. But there are cases when the risk factor will go to zero, despite the fact that there are certain costs for the storage of such stock.

At the same time, [39] considers the problem when the cost of raw materials in the main production is a random variable with some intensity per hour, when the systematic supply of raw materials to some extent creates a shortage of raw materials with constant demand in the main market. It is assumed that the value is the optimal value, which determines the absence of shortage and balance of raw materials, during which the total consumption of raw materials is equal to the volume of its supply has a gamma distribution with parameters: the volume of raw material supply in conventional units of value and the intensity of raw material costs per hour in conventional units of value. The flow of events with a constant intensity of raw material costs in conventional units of cost per hour is considered, the random variable is the time required for the occurrence of a given number (volume of raw material supply) of events. It is concluded that if market demand is constantly declining, it is necessary to consider the assortment component in terms of diversification of basic production.

MATERIALS AND METHODS

The study used a statistical method based on the systematization and processing of statistical data. Relative frequency histograms are constructed for the set of observed X objects. Variants (observations) from the smallest value x_{min} to the largest x_{max} are divided into several segments of equal length h . Then calculate the sum

of the relative frequencies of the values of the variant of the X , which belong to each of the obtained segments. If in the k -th segment ($k=1,2,\dots$) the number of observed variants is equal to n_k , then construct a rectangle II_k , the basis of which will be the k -th segment of length h , and the height will be $\frac{n_k}{n}$, where n is the number observations.

Next, using the results of the constructed sample, found point statistical estimates of the unknown parameters of the random variable X : mean and standard deviation.

From the form of the constructed histogram make assumptions about the law of distribution of general population. The hypothesis of the distribution of the general population according to some selected criterion is tested.

After selecting a certain agreement criterion, the set of all its possible values is divided into two subsets that do not intersect: one of them contains the values of the criterion in which the main hypothesis is rejected (critical region), and the second – in which it is accepted (hypothesis acceptance area). To find the critical area, you need to find the critical point K_{cr} , which separates the critical area from the area of acceptance of the hypothesis. To do this, set a fairly small probability – the level of significance of α , and then look for a critical point, taking into account the requirement.

The following continuous distributions and the central limit theorem were used:

- normal distribution: The general form of its probability density function is:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right) \quad (1)$$

The parameter μ is the mean or expectation of the distribution, while the parameter σ is its standard deviation;

- uniform distribution: The probability density function of the continuous uniform distribution is:

$$f(x) = \begin{cases} \frac{1}{b-a} & \text{for } a \leq x \leq b, \\ 0 & \text{for } x < a \text{ or } x > b \end{cases} \quad (2)$$

$$\text{mean} = \frac{a+b}{2}, \quad \text{standard deviation} = \frac{b-a}{2\sqrt{3}}$$

- erlang distribution: The probability density function of the Erlang distribution is:

$$f(x; k, \lambda) = \frac{\lambda^k x^{k-1} e^{-\lambda x}}{(k-1)!} \quad \text{for } x, \lambda \geq 0, \quad (3)$$

$$\text{mean} = \frac{k}{\lambda}, \quad \text{standard deviation} = \frac{\sqrt{k}}{\lambda}$$

The central limit theorem (CLT) establishes a connection between the distribution of the sum of explosives and its limit form – the normal distribution. CLT states that with a sufficiently large number of equally distributed random variables that have the same mean μ and standard deviations σ , the sum of these quantities is approximately distributed over the normal distribution with the parameters:

$$\text{mean} = n\mu, \quad \text{standard deviation} = \sqrt{n}\sigma$$

The calculations were performed using the **numpy** library for the **Python** programming language.

RESULTS AND DISCUSSION

Parameter distributions and critical regions

Determine the minimum size of the reserve required to ensure that the probability that the reserve will be insufficient does not exceed some value of p (usually $p < 0.1$). Let's make a designation: V – the size of the demand for raw materials between two consecutive purchases of raw materials, S – the size of the purchasing party of raw materials, R – the reserve of raw materials. For a continuous production process, the values of V , S and R must meet the conditions:

$$P(V > S + R) = p$$

when probability p is the state of insufficient reserve.

The need for materials for products is calculated in detail according to the norms for each part that is part of the product, and for each type of material separately.

Consider the process of purchasing parts at the enterprise “Kyiv Central Design Bureau of Valves”, where in the production process you need to periodically purchase more than 60 different parts. Without limiting the generalities, the analysis made the purchase of a single part, which is a necessary component in the production process, namely “Plate XNEX 080616TR-ME09 F40M (SECO 552)”.

Using the statistics of purchases of parts for the period 2013-2021 [40], it is seen that the difference in dates between two consecutive purchases of the above part is distributed according to the normal distribution with a sample average value – 60 days and standard deviation – 14 days (Fig. 1). The differential function for this distribution has the form:

$$f(T; 60, 14) = \frac{1}{14\sqrt{2\pi}} \exp\left(-\frac{(T-60)^2}{392}\right) \quad (4)$$

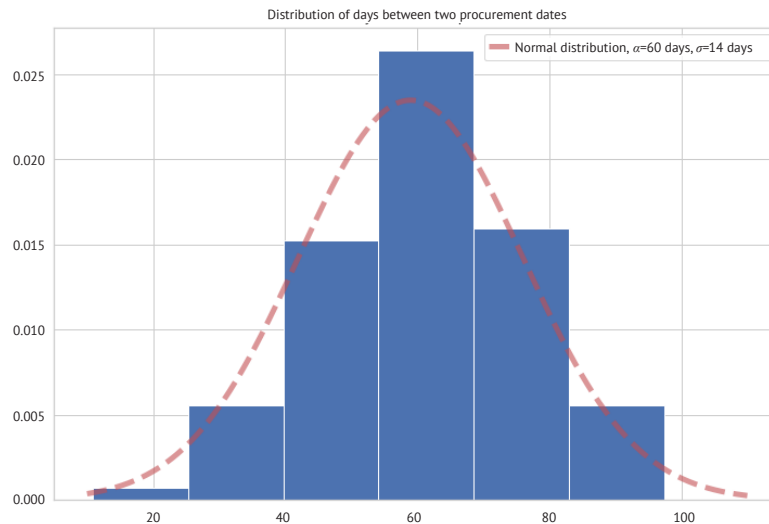


Figure 1. Histogram of relative frequencies between the dates of two consecutive purchases and the graph of the function of a normally distributed random variable V with parameters $\alpha=60$, $\sigma=14$

Source: authors' elaboration

In Figure 2 shows the critical area for a normally distributed random variable with parameters $\alpha=60$, $\sigma=14$ for $\alpha=0.05$, which corresponds to the value of the random variable $T_\alpha=84$ – the number of days between purchases. The area of the shaded area $T \in (T_\alpha; +\infty)$ is equal

to the probability $\alpha=0.05$ that characterizes the state of insufficient reserve (Fig. 2). For the production process, this will mean that if the number of days exceeds 84, then the probability of continuous production will be only 0.05.

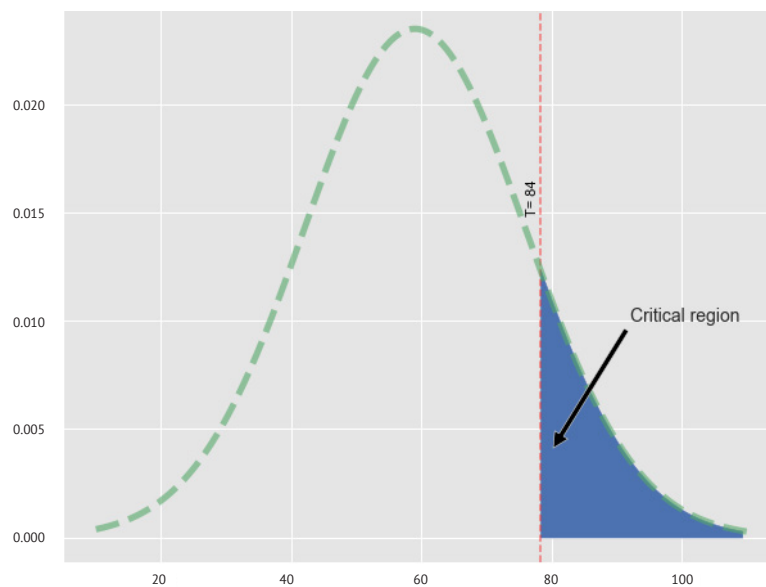


Figure 2. Critical region for a normally distributed random variable T with parameters $\alpha=60$, $\sigma=14$ for $\alpha=0.05$

Source: authors' elaboration

According to the statistics of procurement of parts for the period 2013-2021 [40], the amount of individual parts "Plate XNEX 080616TR-ME09 F40M (SECO 552)" during each purchase is described by a uniform distribution with parameters $a=10$, $b=40$ ($M(X)=25$, $\sigma(X)=5\sqrt{3}$).

Purchases of parts take place on average every 2 places. Thus, the differential function of the uniform distribution has the form (Fig. 3):

$$f(x) = \frac{1}{25}, x \in [10; 40] \quad (5)$$

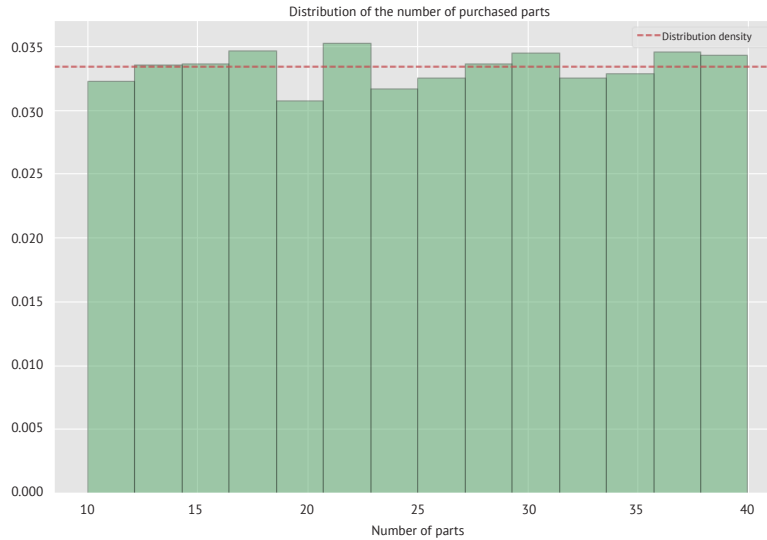


Figure 3. Histogram of relative frequencies of volume of purchases of details and density of uniform distribution with parameters $a=10, b=40$

Source: authors' elaboration

Using the central limit theorem, it can be stated that during the year the procurement volume of parts of the type "Plate XNEX 080616TR-ME09 F40M (SECO 552)", distributed according to the normal distribution with parameters, $a=6 \cdot 25=150, \sigma=\sqrt{6 \cdot 5 \cdot 3}=15\sqrt{2}$ (On average,

6 purchases are made per year). The differential function of the normal distribution has the form (Fig. 4):

$$f(S; 150, 15\sqrt{2}) = \frac{1}{30\sqrt{\pi}} \exp\left(-\frac{(S - 150)^2}{900}\right) \quad (6)$$

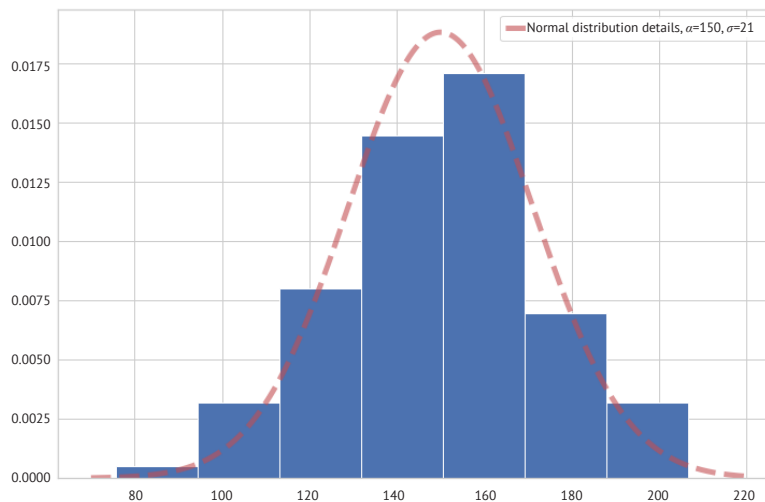


Figure 3. Histogram of relative frequencies of the volume of parts purchased for a calendar year and the graph of the function of the normally distributed random variable S with the parameters $a=150, \sigma=15\sqrt{2}$

Source: authors' elaboration

Figure 5 shows the Gaussian curve and the critical region for a normally distributed random variable with parameters $a=150, \sigma=15\sqrt{2}$ for $p=0.05$, which corresponds to the value of the random variable $S=115$ – the

number of parts. The area of the shaded area for $S \in (0; S_p)$ should be equal to the probability p , which is calculated by the Laplace function and characterizes the state of insufficient reserve.

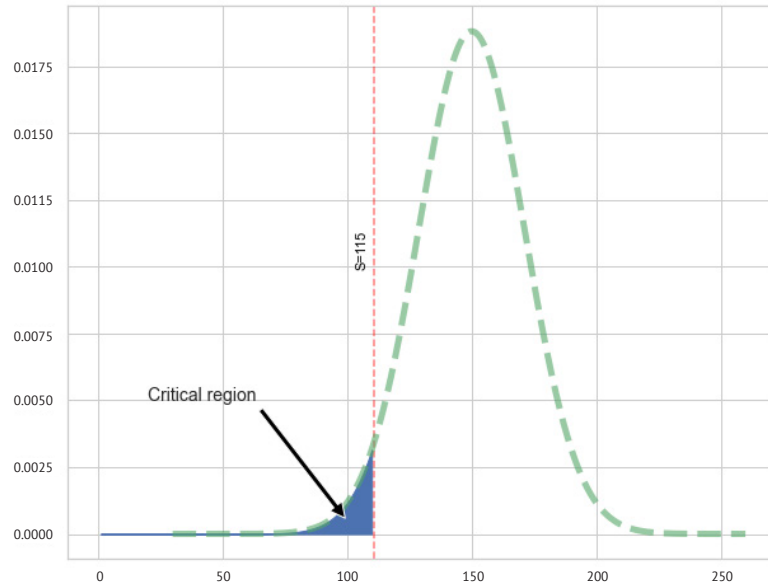


Figure 5. Critical region for a normally distributed random variable S with parameters $a=150, \sigma=15\sqrt{2}$ for $p=0.05$
Source: authors' elaboration

Replacement of used parts of the type “Plate XNEX 080616TR-ME09 F40M (SECO 552)” with new ones is described by Erlang distribution with parameters $k=2, \theta=5$ ($R \sim \Gamma(2;5)$), which corresponds to the average number of days – 10, with a variance – 50. The differential Erlang distribution function has the form:

$$f(R; 2.5) = R \cdot \exp\left(-\frac{R}{5}\right), \Gamma(2) = \int_0^{+\infty} R \cdot \exp(-R) dR \quad (7)$$

Figure 6 shows a histogram of the relative frequencies of the days of replacement of used parts and a graph of the function distributed according to Erlang distribution random variable R with parameters $k=2, \theta=5$.

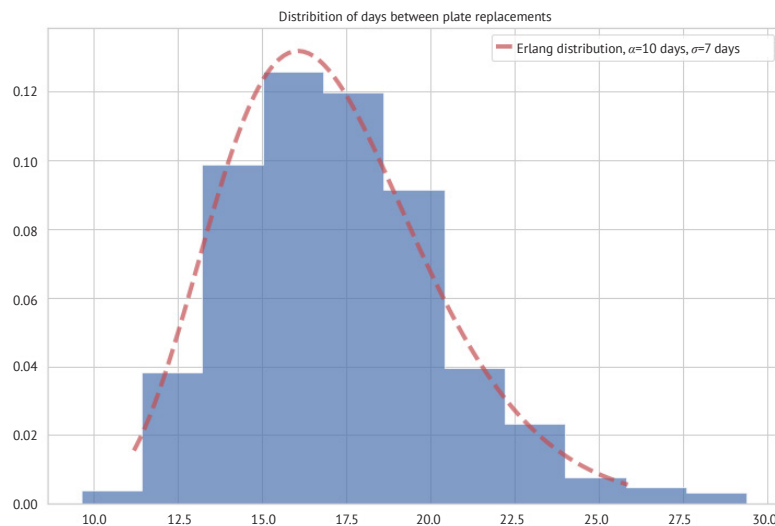


Figure 5. Histogram of relative frequencies of days of replacement of used parts and graph of the function of random variable R distributed according to Erlang distribution with parameters $k=2, \theta=5$
Source: authors' elaboration

According to the central limit theorem, it is assumed that during the year the amount of spent parts of the type “Plate XNEX 080616TR-ME09 F40M (SECO 552)”, distributed according to the normal distribution with parameters, $a=36 \cdot 10=360, \sigma=\sqrt{36 \cdot 50}=30\sqrt{2}$ (36 replacement parts per year).

Figure 7 presents a histogram of the relative frequencies of the volume of replacement of parts during the calendar year and a graph of the function of the normally distributed random variable R with parameters $a=300, \sigma=30\sqrt{2}$.

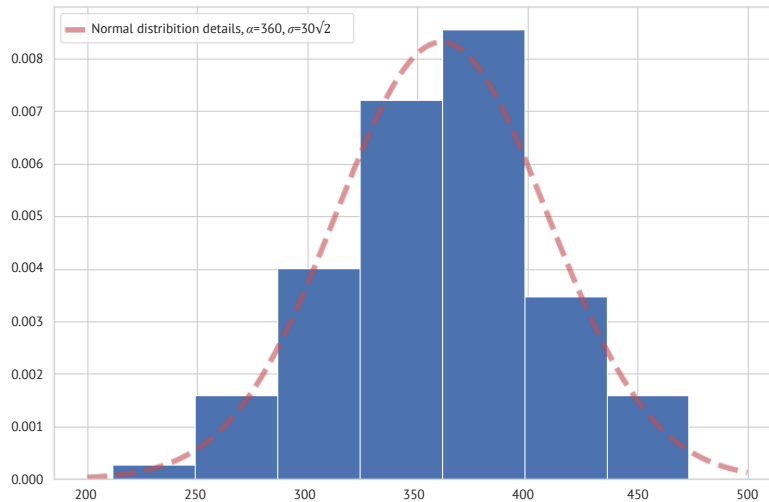


Figure 7. Histogram of relative frequencies of replacement volume during a calendar year and graph of the function of a normally distributed random variable R with parameters $\alpha=300$, $\sigma=30\sqrt{2}$

Source: authors' elaboration

Calculate the size of the reserve of parts depending on the established risk factor. Table 1 for the different values of p shows the value of the difference in days between parts purchases, purchase values and

parts reserves that meet the laws of distribution of random variables T , S and R with the corresponding parameters, as well as the critical value V_p of parts demand during production.

Table 1. Critical values days, sizes, reserves, demands (T , S_p , R_p , V_p)

p	T	S_p	R_p	V_p
0.01	93	101	261	362
0.02	89	106	273	379
0.05	84	115	290	405
0.1	78	123	306	429

Source: authors' elaboration

From Table 1 we can draw the following conclusion: the longer the period between purchases in days T , the smaller the value V_p that characterizes the process of continuous production (if there are less than 405 parts or the period between purchases exceeds 84 days, it means that the probability of continuous operation is 0.05, or that with a probability of $1-0.05=0.95$ it can be argued that there will be a simple production).

Inventories are the means of production that have arrived in the warehouses of the enterprise, and are waiting to enter the production process. These stocks allow to provide release of materials in shops and on workplaces according to requirements of technological process. It should be noted that the creation of stocks distracts a significant amount of material resources. Reducing inventories reduces the cost of their maintenance, reduces costs, accelerates the turnover of working capital, which ultimately increases profits and the feasibility of production. Therefore, according to the authors, optimizing the size of stocks is an important task. The reserve in case of violations in the supply or increase in output is

characterized by a certain value and is restored after receiving the next batch of materials. The standard of insurance stock of materials is determined by the interval of backlog of deliveries or by actual data on replenishment of stocks. Finding the size of such a reserve is an urgent problem. The company should strive to minimize inventories, but stocks of raw materials should be close to optimal. The point of economically justified order is the equilibrium point of the cost of purchase and storage. For some stocks, purchase costs are negligible, and the main burden falls on storage costs. Costs can be minimized if low-cost parts are purchased in large batches at long intervals, and expensive ones more often, but in small batches. If the terms of placing the order satisfy the company, the smallest number of parts is ordered at the appointed time of submission of the request. Maintaining inventories at a predetermined level is one way to increase the company's profits.

Given the above research, it can be argued that one of the main tasks is to find the optimal value for each product, or to determine the minimum level of stocks for

continuous production. The optimal amount of reserves should correspond to the economically optimal volume of the purchasing party plus some guarantee stock. The optimal volume of purchases should be equal to the volume of stocks used in the production process for production. When managing production or inventories, there are two main questions: the time of renewal of inventories and what should be its size. Obviously, stocks require certain costs for their storage until they are sold. Moreover, the company's losses increase due to the part of working capital that is invested in stocks. Therefore, it is important to build a mathematical model that describes the system under study, and on its basis to find the optimal ratio between costs and benefits of the selected level of stocks and determine what stocks for each group of goods or raw materials are sufficient.

CONCLUSIONS

Thus, taking into account the degree of uncertainty associated with the structure of demand and the time of use of stocks at the enterprise, the authors chose probabilistic models that allow flexible change of simulated demand and take this into account in forecasting. The process of purchasing parts at enterprise "Kyiv Central Design Bureau of Valves" for the period 2013-2021 is

considered, while it is proved that the difference in dates between two regular purchases of one individual part is distributed according to the normal distribution, and the amount of individual parts at the time of each purchase is described by a uniform distribution.

Using the central limit theorem, it is shown that during the year the purchase volume of parts is distributed according to the normal distribution. It is also proved that the replacement of used parts with new ones is described by Erlang distribution. The histogram of relative frequencies of volume of replacement of details during a calendar year is presented. The value of the difference in days between the procurement of parts, the value of purchases and the reserve of parts that correspond to the distributions of random variables with the appropriate parameters, as well as the critical value of the need for parts in the production process. This made it possible to draw conclusions about the optimal values of the reserve for continuous operation of production, indicating the conditions under which downtime may occur. Therefore, the problem of finding the optimal reserve stock, when the random value of the size of raw material needs is distributed over different time intervals and according to different laws, including different from normal, may be the subject of further research.

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Управління запасами на підприємстві із застосуванням імовірнісних моделей

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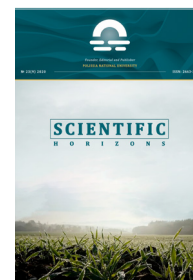
Анотація. З метою забезпечення неперервної виробничої діяльності підприємства усіма потрібними ресурсами будується система управління виробничими запасами. Метою цього дослідження є побудова ймовірної моделі, яка може бути запропонована як нова модель інвентаризації, за допомогою якої встановлюються взаємозв'язки факторів періоду між закупівлею деталей та тривалістю їх придатності, що впливають на управління запасами. Методи дослідження засновані на ймовірнісному підході з використанням неперервних законів розподілу. Використовуючи статистичний метод, знайдені точкові оцінки для досліджуваних параметрів: середнього і середньоквадратичного відхилення. Побудовані гістограми відносних частот між датами двох чергових закупок, обсягу закупок деталей та днів заміни відпрацьованих деталей. Проілюстровані критичні області для досліджуваних параметрів. Розраховано значення різниці в днях між закупками деталей та величин закупок деталей, які відповідають нормальним законам розподілу випадкових величин з відповідними параметрами, а також критичні значення потреби в деталях в процесі виробництва. Знайдено розмір резерву деталей, який відповідає закону розподілу Ерланга, в залежності від встановленого коефіцієнту ризику. Для різних значень цього коефіцієнту наведено значення різниці в днях між закупками деталей, величин закупок і резерву деталей, які відповідають законам розподілу випадкових величин, а також критичне значення потреби в деталях в процесі виробництва для уникнення простою виробництва. Використовуючи центральну граничну теорему, показано, що закупівельний обсяг деталей та обсяг відпрацьованих деталей розподілені за нормальним законом. У дослідженні зроблено висновки, що ймовірнісний підхід є основою прогнозування управління запасами на підприємстві, що враховує ризики, пов'язані з визначенням оптимальної потреби в сировині на підприємстві

Ключові слова: запаси, витрати, резерв, нормальний розподіл, розподіл Ерланга

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Foreign-Economic Priorities of the Development of Investment Infrastructure of Agri-Food Production Entities

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Abstract. The article considers foreign economic priorities of investment infrastructure development of agri-food production entities of Ukraine. A comprehensive methodological approach to assessing the effective diversification of investment infrastructure of agri-food production entities has been developed. It is substantiated diagnostics of attracting foreign direct investment in the development of agri-food production allows forming an export-oriented type of state economy, identify the main sources of technical equipment for agribusiness and master innovative technologies, form production potential and mechanism for implementing strategic investment goals. An algorithm for calculating the level of attractiveness of the investment infrastructure of agri-food production entities has been developed. The dynamics of foreign trade in agri-food products of the steppe zone of Ukraine is given. The amount of foreign direct investment from foreign economic activity of agri-food production entities in the economy of the regions of the Steppe zone of Ukraine is determined. The geography of agri-food exports of the steppe zone of Ukraine in the international trade markets is presented. The forecast volume of exports of agri-food products in the regions is calculated and the limit parameters of indicators of attractiveness of investment infrastructure of subjects at attraction of direct foreign investments from foreign economic operations are defined

Keywords: foreign direct investment, foreign economic activity, investment infrastructure, agri-food production entities, export, import



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INTRODUCTION

The rapid growth of world trade determines one of the most important trends in the global economy – a high degree of foreign economic activity, increasing the volume of which allows to form an export-oriented type of economy, which is typical of Western Europe and North America. In this trend, the positions of other countries are strengthening, such as China, “4 Asian Tigers”, India, etc. In addition, foreign economic integration of developed countries in the technological process of ensuring a high-quality structure of production in countries with weak economies requires finding alternative scenarios for investment development of agri-food production in international trade relations, given competitive advantages in international markets.

It should be noted that agri-food production of countries with weak economies requires specific areas to optimize the impact of numerous external and domestic factors, including – the dynamics of increasing world trade in agriculture and processing industry, stabilization of foreign economic export potential and foreign investment. At the same time, taking into account the specifics of the formation of the cost of agri-food production, it should be noted that the conditions and restrictions of foreign trade significantly affect the final price of products, which determines the level of its competitiveness. This requires assessing the impact of international markets on changes in the competitiveness of agri-food production, which differs in many groups of indicators: prices, production volumes, export-import of goods by country, consumption in domestic markets of exporting and importing countries, the number of global exporting competitors, major world importers-consumers, the size of customs tariffs, the volume of quotas for duty-free imports and temporary quotas, the volume of stocks of exporting and importing countries, the degree of investment development of agri-food production in product (market) terms, the share of foreign exchange earnings, etc.

Research of the newest problems of formation of competitiveness of agri-food sector in the conditions of globalization is made in the works of I. Iholkin [1], S. Kvasha, V. Vlasov and N. Kryvenko [2], A. Kliuchnyk [3], Yu. Zaitsev [4], A. Zavhorodnii [5], Zh. Zosymova [6]. The following works are devoted to the study of the problems of development of foreign economic activity of agri-food enterprises: Yu. Kozak, N. Prytula and O. Yermakova [7], P. Leonenko and O. Cherepnina [8]. In turn, the problems of foreign trade development, in particular agricultural products, are a priority for the following scientists: M. Lepekha, H. Svyrydenko [9], D. Lukianenko, A. Poruchnyk and L. Antoniuk [10], M. Makarenko [11], M. Zos-Kior and N. Sokolova [12]. Based on the obtained results of formation of competitiveness of agri-food sector in the conditions of globalization, a powerful school of international economic relations was formed, where trade relations play a special role, the research of which

is carried out by C. Berry [13], N. Čučković, J. Krešimir, V. Vučković [14], J. Davis and R. Gilbert [15], M. Gort [16], I. Kirzner [17], M. Moraliyska [18], M. Porter [19], M. Rafat [20], D. Rodrik [21], J. Svobodová, L. Dömeová and A. Jindrová [22], W. Su, D. Zhang, C. Zhang, J. Abrhám, M. Simionescu, N. Yaroshevich and V. Guseva [23]. Despite the obtained scientific achievements, the doctrine of agri-food development requires further research, eliminating negative crises and stimulating territorial socio-economic growth, primarily by determining foreign economic priorities for investment development of agri-food production in the context of international trade relations.

The priority of our study is the implementation of a comprehensive methodological approach to assessing the effective diversification of investment infrastructure of agri-food entities, which under the influence of foreign direct investment in agribusiness determine investment opportunities in foreign economic activity, provide foreign exchange earnings to the economy of the state, activate the export potential of regional producers in international trade markets.

MATERIALS AND METHODS

Foreign economic activity as a system of economic relations, due to the movement of commodity and financial resources in the context of globalization of agri-food production is a vector of economic development of any country. It defines the activities of the subjects of economic relations of the state and foreign entities engaged in cooperation and partnership both on its own territory and abroad. Foreign economic priorities of agri-food production entities are often identified with the implementation of foreign trade operations, the share of which reaches 80% of the total volume of international relations. International diversification, which takes place under the influence of technological processes for commercial and social purposes, enables entrepreneurs to effectively use existing marketing levers in the domestic market and form proposals at the global level, constantly increase investment efficiency, increase profits, reduce existing business risks through effective business environment management. Thus, the effective functioning of the economy of agricultural enterprises cannot happen without a developed system of foreign economic relations in the agricultural sector. The inclusion of the agri-food sector in the system of world economic processes and the formation of effective strategies for foreign economic activity of agricultural enterprises has a positive effect on the development of the agricultural sector and contributes to increasing the technical level of production, eliminating shortages of certain goods, rational use of natural resources and improving the living standards of the population [22].

The general approaches to assessing the effectiveness of the strategy of diversification of investment infrastructure of agri-food production entities (AFP) are

exports; joint venture; direct investment [2]. At the same time, a comprehensive system for assessing the diversification of investment infrastructure in foreign economic activity of agricultural entities provides: 1) identification of its strengths and weaknesses based on critical analysis of economic effects and economic efficiency of each type and direction of foreign economic transactions; 2) identification of development reserves and minimization of the complex of costs; 3) optimization of the structure of foreign economic operations and increase their efficiency.

In terms of the methodological approach to assessing the effectiveness of the implementation of measures for the development of investment infrastructure of foreign economic activity from foreign trade operations, the following indicators are most often used: indicators of full efficiency of exports and imports, as well as the effect of their use.

Full export performance indicator [24]:

$$ke = \frac{V_e}{S_e} \quad (1)$$

where V_e – the value of exported products at foreign trade prices or foreign exchange earnings from sales of products on the international market; S_e – the cost of purchasing export products or the cost of purchasing national goods for sale on the international market.

Export effect [24]:

$$E_e = V_e - S_e \quad (2)$$

Full import efficiency indicator [24]:

$$k_i = \frac{V_i}{S_i} \quad (3)$$

where V_i – the value of imported products at foreign trade prices or foreign exchange funds spent on the purchase of imported goods; S_i – the cost of purchasing national goods similar to imported ones.

Effects from imports [24]:

$$E_i = V_i - S_i \quad (4)$$

The implementation of foreign economic priorities for the development of investment infrastructure (AFP) at the regional level is diagnosed by defining a system of quantitative and qualitative indicators, which include the openness ratio, the index of actual comparative advantage, the balance of international trade and more. The description of the most important indicators allows:

1) to quickly and objectively form an idea of the state, development trends and efficiency of technological processes of AFP for the entry of products and goods on the world market;

2) to determine the level of competitiveness of agricultural and food products;

3) to establish a promising commodity and geographical structure of international trade in agri-food products;

4) to identify the weaknesses and strengths of the enterprises of the region's AFP as participants in foreign economic activity [2].

To determine the level of risk of territorial orientation of export-import operations of agri-food products, we propose to use the index of risk of geographical diversification (IDR), which helps to determine the level of risk of product groups in their exports and imports. Geographical diversification of exports is the distribution of export supplies of goods among a large number of importing countries in order to reduce the risk of possible losses of markets, increase the efficiency of foreign trade operations, resulting in priority conditions for international relations, reduces the risk of export transactions (connected with political, economic, legal factors), as well as expanding opportunities to overcome negative situations when changing market conditions [24].

In view of the above, effective geographical diversification of exports (imports) is associated with a more or less even distribution of export (import) products among a relatively large number of importing (exporting) countries. The risk index of geographical diversification is calculated by formula (5), [24]:

$$IDR = \sum_{i=1}^m E_i - m/n \quad (5)$$

where n – is the total number of importing countries of a particular product; m – is the number of importing countries whose exports exceed or equal to the average value of exports formula (6), [24]:

$$\frac{1}{m} E_i \geq E_c, E_c = E/n \quad (6)$$

where $\sum_{i=1}^m E_i$ – the volume of exports of certain goods in m countries.

In turn, IDR depends on the total number of countries to which the goods are exported, the number of countries to which exports exceed or equal to the average value, as well as the total volume of exports to these countries. The value IDR ranges from 0 to 1, because [24]:

$$\sum_{i=1}^m E_i \geq mE_c \quad \text{or} \quad \sum_{i=1}^m E_i \leq 1 \quad (7)$$

Obviously, the smaller the number of countries whose exports exceed E_c , the greater the value IDR, and vice versa. That is, with significant volumes of exports to a small number of countries, there is a diversification risk, and when combined with other risks (political, economic, etc.) poses a threat to exports of this product. If exports are evenly distributed (i.e., with an increase in the number of countries whose exports exceed E_c), the risk of exporting a particular product decreases [24]. However, most often the efficiency of the investment infrastructure of agri-food production entities at the

state (or regional) level is determined through the use of a system of absolute indicators of export-import operations, etc.

Methodical principles of diagnosing the state of attracting foreign direct investment in the development of agri-food production allows to form an export-oriented type of state economy, identify the main sources of technical equipment for agribusiness and master innovative technologies, form production potential and mechanism for implementing strategic investment goals of the region. Most countries with weakened economies need to significantly increase investment in the real sector of the economy, create an effective and adapted system for attracting investment capital to ensure economic growth in the regions, improve the socio-economic situation and improve the welfare of the population. It is in the field of agri-food production that investment activity is a source of food and economic security of the state, a guarantor of the development of its industries in the regions and the implementation of environmental principles of natural resources. Accordingly, the stabilization of the macroeconomic situation in the country allows not only to optimize the investment processes of agri-food production (AFP), but also to ensure a sufficient level of investment activity of economic entities at the international level.

The efficiency of attracting foreign investment is closely related to increasing the economic efficiency of agri-food production and the assessment of international cooperation takes into account the specific features of this sector at the regional level, namely: the degree of foreign investment in industries and the effectiveness of innovative technologies to improve processing quality and storage of agricultural products, use of resources, saturation of the domestic market with high quality food, creation of new jobs, increase of export potential, establishment of economic relations between economic entities, etc. [18].

Implementation of foreign economic priorities for the development of investment infrastructure of agri-food production is associated with the formation of a comprehensive, dynamic and structurally balanced system that can sufficiently intensify investment processes, ensure production and technological modernization, expand production capacity, increase efficiency, and strengthen competitiveness of agro-industrial production in general. The system of investment infrastructure of agri-food

production acquires the character of horizontal-vertical cooperation (in the form of a “map” of institutional elements at the intersection of planes “management levels – functions”), where horizontal interaction is manifested through the creation and coordination of institutional elements of the system at the micro, meso, sectoral, macro and global levels; vertical integration - the interaction of elements of the system in order to implement the main functions, which should perform a full and developed investment infrastructure of the industry complex. At the same time, the integrated assessment of the investment infrastructure of agri-food entities in the regions of the country should include a set of quantitative and qualitative indicators that determine its impact on foreign economic priorities of cooperation and attracting foreign investment in the agricultural sector. Quantitative indicators in their entirety are ranked according to the level of impact on the ratio of investment resources in the fixed capital of agri-food entities, which indicates their investment activity, while identifying indicators that determine its risk component [25]. The comparison of quantitative and qualitative indicators is made using a scale, according to which each individual indicator receives a weighting factor according to the method of priorities. That is, the foreign economic priorities of agri-food production entities depending on the value of the investment infrastructure indicator in the region are classified as [26]: low investment infrastructure of agri-food production entities in the region – $K < 0.05$; below average – $0.05 < K < 0.1$; intermediate level – $0.1 < K < 0.2$; above average – $0.2 < K < 0.4$; high – $K > 0.4$.

It should be noted that for most agribusiness entities it is important to implement investment projects. One of the most important criteria for evaluating investment projects is the financial probability of its implementation, which is characterized by the availability of sufficient financial opportunities. To determine the effectiveness of the project, quantitative characteristics are used, which are based on individual qualitative characteristics.

The main methods and indicators for assessing the effectiveness of investment projects are given in (Table 1). The choice of investment option can be made by discounting future income. Entities of agri-food production, implementing an investment project, evaluate it based on a comparison of expected income and costs for the acquisition and operation of such a project.

Table 1. The main methods and indicators for evaluating the effectiveness of investment projects

Indicator	Calculation algorithm	Legend
Static methods in assessing the effectiveness of investment projects		
Payback Period of Investments (PP)	$PP = \min n$, at which $\sum_{k=1}^n DK_k \geq I$	where DK_k – annual income from the project for the k -th year; I – investment costs; n – the number of years of calculation
Accounting Rate of Return (ARR)	$ARR = \frac{NP}{1/2 \times (CL + I)}$	The indicator is often compared with the rate of return on advanced capital, which is calculated by dividing the total net profit of the enterprise by the total amount of funds advanced to its activities (the sum of the average net balance)
Dynamic methods in assessing the effectiveness of investment projects		
Present Value (PV)	$PV = \sum_{k=1}^n \frac{DK}{(1+r)^k}$ $NPV = \sum_{k=1}^n \frac{DK_k}{(1+r)^k} - I$	
Net Present Value (NPV)	If the investments related to the future implementation of the project are carried out in several stages (intervals – m years), then the calculation – m years), then the calculation NPV is as follows:	where DK – the amount of cash flow; I – the amount of initial investment (costs); r – discount rate (rate); n – project implementation time
	$NPV = \sum_{k=1}^n \frac{DK_k}{(1+r)^k} - \sum_{k=1}^m \frac{I}{(1+r)^k}$	
Internal Rate of Return (IRR)	$IRR=r$, at which $NPV=IRR=0$	$IRR>CC$ – the project should be accepted; $IRR<CC$ – the project should be rejected; $IRR=CC$ – the project is neither profitable nor unprofitable. Where CC – cost of capital
Profitability Index (PI)	$PI = \sum_{k=1}^n \frac{DK_k}{(1+r)^k} \div I$	$PI>1$, the project should be accepted; $PI<1$ – to abandon it; $PI=1$, the project is neither profitable nor unprofitable
Modified internal Rate of Return (MIRR)	$\sum_{k=0}^n \frac{OC_k}{(1+r)^k} = \frac{\sum_{k=1}^n PC_k \times (1+r)^{n-k}}{(1+MIRR)}$	where PC_k – cash inflows in the period; OC_k – cash outflow in the period (in absolute terms); r – discount rate (or cost of capital); n – duration of the project
Discounted Payback Period (DPP)	$DPP = \min n$, at which $\sum_{k=1}^n \frac{DK_k}{(1+r)^k} \geq I$	Under the condition of discounting, the payback period increases, i.e., always $DPP>PP$. Given a low discount rate, typical of a stable economy, the indicator improves the result by a small amount, but at a higher discount rate changes the estimated value of the payback period (i.e., a project acceptable by criterion PP , may be unacceptable by criterion DPP)

Source: summarized by the authors according to data [27]

The projected income is calculated from the annual income from the operation of capital implementations (technologies) during their validity, while the investment is made simultaneously. In this regard, the amount of investment in capital implementation is determined in order to obtain the required income for some time [26]. Such calculations are called discounting of future income, and the amount to be paid for capital investments at present – the discounted value. The discounted value depends on the interest rate. The discounted value (D_c) for the same amount of annual income is calculated by formula (8) [26]:

$$D_c = O / (1 + I_r)^x \quad (8)$$

where: O – the amount to be received by the agri-food entity at the annual interest rate of the bank (I_r); x – the number of years during which the annual income is expected.

If the annual return on investment is different, the size of the discounted value (D_p) is determined by formula (9) [28]:

$$D_p = \frac{O_1}{(1 + I_r)^1} + \frac{O_2}{(1 + I_r)^2} + \dots + \frac{O_n}{(1 + I_r)^n} \quad (9)$$

where O_1, O_2, O_n – expected amounts of annual income, EUR; n – the number of years during which annual income is expected.

When making decisions about long-term investments, there is a need to predict their effectiveness. To this end, a long-term analysis of income and expenses is made. The methods that are taken into account in the analysis of the diversification of investment infrastructure of the agri-food entity are divided into 2 groups. It depends on the time factor: static (based on accounting estimates); dynamic (based on discounted estimates). Static methods, where cash flows that arise at different times are considered equivalent (i.e., the concept of change

in the value of capital over time is not used) and are characterized by indicators: PP, ARR. Dynamic methods, where the cash flows that appear during the project, are reduced to an equivalent basis by discounting and ensure the comparability of different cash flows, are characterized by indicators: NPV, IRR, PI, DPP, MIRR. The algorithm for calculating the level of attractiveness of the investment infrastructure of agri-food production entities is proposed in Figure 1.

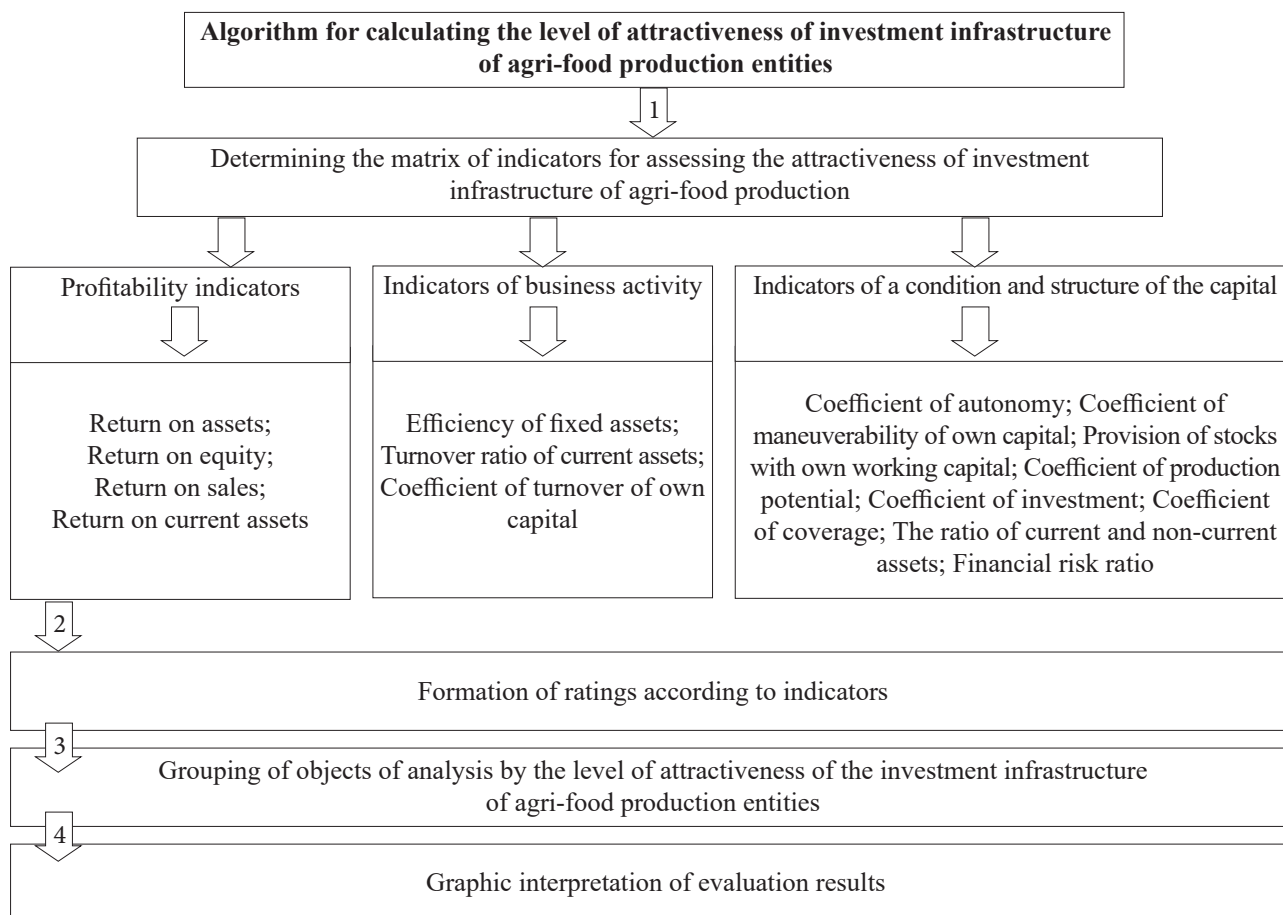


Figure 1. Algorithm for calculating the level of attractiveness of investment infrastructure of agri-food production entities

Source: developed by the authors

The scientific society uses methods of rating the attractiveness of the investment infrastructure of agri-food entities, based on their financial and economic indicators, among which are: Global 1000; Fortune 500; Business Week 1000. These methods are used to estimate the value of assets, income, quality of investment,

growth of current and non-current assets and the level of market value of enterprises [29]. Estimation of attractiveness of investment infrastructure according to the offered algorithm is defined for subjects of agri-food production on the basis of the analysis of the corresponding groups of indicators given in (Table 2).

Table 2. Indicators of attractiveness of investment infrastructure of agri-food production entities

Indicators	Determination algorithm	Score (1 point)
<i>Profitability indicators</i>		
Return on assets	Net profit (loss) / Average annual value of assets	>0.14
Return on equity	Net profit (loss) / Average annual cost of equity	>0.2

Table 2, Continued

Indicators	Determination algorithm	Score (1 point)
Profitability of realization	Gross profit (loss) / Net income from sales	Increasing
Return on working capital	Net profit (loss) / Average annual value of current assets	Increasing
<i>Indicators of business activity</i>		
Efficiency of fixed assets	Net income from sales / Average annual value of fixed assets	Increasing
Turnover ratio of current assets	Net income from sales of products / Average annual value of current assets	Increasing
Equity turnover ratio	Net income from sales / Average annual cost of capital	Increasing
<i>Indicators of the state and structure of capital</i>		
Coefficient of autonomy	Equity / Balance Currency	>0.5
Equity maneuverability ratio	Own working capital / Equity	Increasing
Provision of inventories with own working capital	Own working capital / Inventories	Increasing
Coefficient of production potential	Current assets + Fixed assets / Balance sheet currency	Increasing
Investment ratio	Non-current assets / Equity + Long-term liabilities and collateral	>1
Coverage ratio	Current assets / Current liabilities	>1
The ratio of current and non-current assets	Current assets / Non-current assets	
Financial risk ratio	Liabilities / Equity	>1

Source: compiled by the authors based on data [30]

Increasing the attractiveness of investment infrastructure of AFP entities and increasing the efficiency of their foreign economic activity depends on the accelerated adaptation of domestic institutions and institutes to market conditions and the formation of an effective, stimulating regulatory framework for their activities in the domestic and foreign markets. Institutional approaches at the state level to support, stimulate and protect national agricultural producers, form the export potential of AFP entities, and optimize the commodity and geographical structure of agricultural exports need to be reviewed. Particular attention should be paid to increasing the share of ready-to-eat products in agricultural exports. At the same time, imports should be dominated not by food, but by technology, modern equipment and resources

for the organization of modern agricultural production. We propose to introduce diagnostics of ensuring the attractiveness of the investment infrastructure for the development of foreign economic activity of the agri-food production entities of the region at the regional (state), sectoral and business levels (i.e., at the macro, meso and micro levels). With this in mind, for such an assessment at the regional (state) and sectoral levels, we propose to use integrated methods of assessment of Macro- and MesolPFEA-analysis (macro- and meso-infrastructure support of foreign economic activity), which allow to determine the system, share value of influence and forecast the dynamics of environmental factors, in particular: customs, consulting, legal, information-analytical, marketing, personnel, insurance, banking, logistics (Fig. 2).



Figure 2. MicroIPFEA-analysis of ensuring the attractiveness of investment infrastructure for the development of foreign economic activity of entities of agri-food production of the region

Source: developed by the authors according to data [31]

At the same time, the basic elements of the development of the investment infrastructure of the region's AFP entities in the implementation of foreign economic activity should be: state administration bodies (State regional administrations, city councils, Customs of the State Fiscal Administration); financial and credit institutions, organizations, investment funds and companies in the region; scientific and research institutions, organizations; subjects of agri-food production; foreign trade firms and intermediaries (commodity exchanges of the agro-industrial complex), insurance institutions and organizations of the region; logistics and forwarding companies; territorial bodies of the State Fiscal Service, the Antimonopoly Committee, the Department of the State Food and Consumer Service. We believe that the proposed comprehensive methodological approach to assessing the effectiveness of diversification of investment infrastructure of agri-food production in foreign economic activity, taking into account all factors and conditions of territorial and sectoral development, should have a basic platform of the above methods, which provide the formation of the analytical basis of the investment business environment, uniting institutions, organizations and economic entities for the sustainable development of the agri-food sector of the regions in order to integrate it into the international economic system for successful business, growth of gross value added in economic areas activities and gross domestic product of the state. This will meet the demand for goods and services, create the

conditions for effective investment and modernization of production, the introduction of innovative technologies. The proposed methods are based on expert assessment of the effectiveness of factors, is a set of quantitative (integrated) effects due to the manifestation of certain factors on the development of foreign economic activity of agri-food production, the relationship and interdependence between which determines their priority.

RESULTS AND DISCUSSION

The modern economic complex of Ukraine consists of socio-economic systems of the regions, each of which has its own characteristics of composition and development. Thus, the dynamics of the volume of export-import operations of the Steppe zone regions, their geographical structure allows the subjects of agri-food production to develop promising areas of foreign trade (Fig. 3).

The total volume of foreign trade turnover of agri-food production in the Steppe zone increased from 2011 by 41.9% to the mark of 102.3 million EUR, i.e., reached a maximum for the period under study, despite the fact that in 2017 its regression to the mark of 73.1 million EUR was recorded. The volume of regional agri-food exports during the study period increased 2 times to the level of 87.3 million EUR, while the level of its growth compared to 2016 was 24.5%. This state is marked by the trend line of the linear function, which is described by the equation with the approximation value $R^2=0.840$.

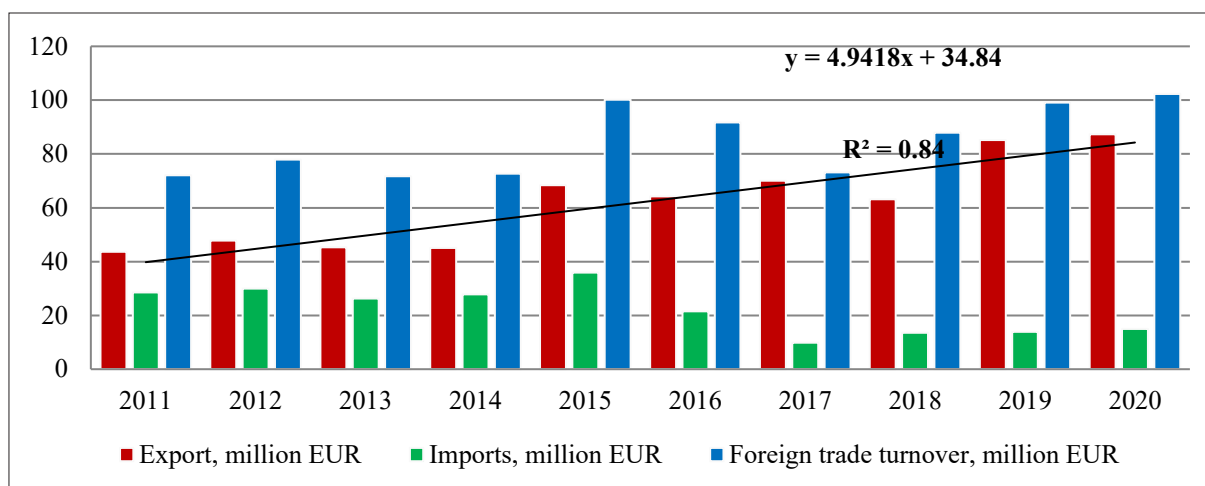


Figure 3. Foreign trade of agri-food products of the regions of the Steppe zone of Ukraine for 2011-2020, million EUR

Source: calculated by the authors according to data [32]

The structure of agri-food exports and imports of the administrative regions of the Steppe zone of Ukraine is presented in Figure 4-5. Thus, the largest volume of agri-food production in the Steppe zone of Ukraine is carried out by the entities of the Mykolayiv region, the volume of which in 2020 amounted to 44.7 million EUR.

At the same time, the increase in exports against the level of 2011 increased by 72.1%, while against 2016 it amounted to only 38.2%. The total volume of export of agri-food products of the Mykolayiv region exceeded the indicator of the Zaporizhzhia region on the average for 2018-2020 on 5.4%, the Kherson region – in 7.2 times.

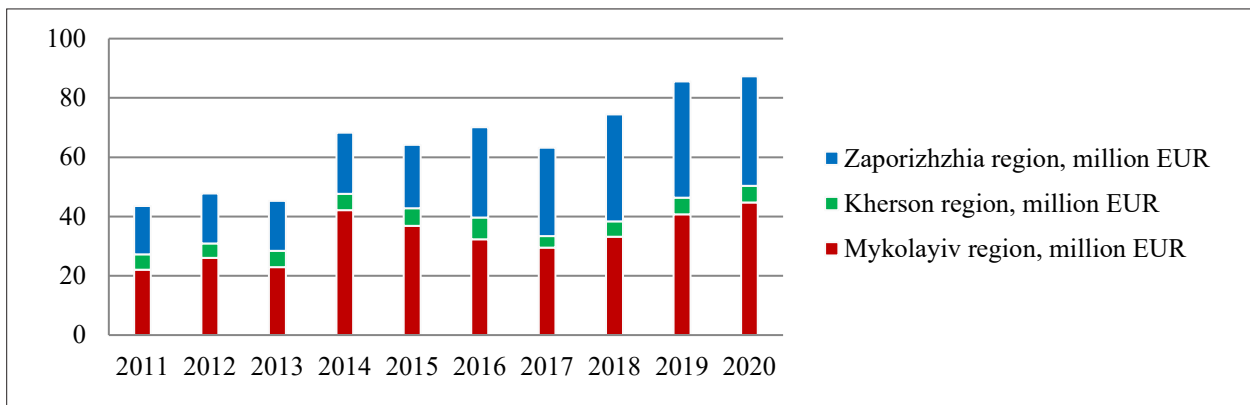


Figure 4. The structure of exports of agri-food products in terms of administrative regions of the Steppe zone of Ukraine for 2011-2020, million EUR

Source: calculated by the authors according to data [32]

The volume of agri-food imports, in contrast to the dynamics of export operations in terms of administrative regions of the Steppe zone of Ukraine, has a negative tendency to decrease (the average value for 2018-2020 – 14.1 million EUR). At the same time, over the last ten years (2011-2020) its volumes have decreased by 49.8% and in relation to the level of 2016 – by 30.7% respectively.

The leader of import operations on agricultural products and food products is the Zaporizhzhia region, but since 2016, there has been a clear trend to slow down the import of agri-food products by 31.5%. On average, in 2018-2020, products were imported only by 10.6 million EUR, but this figure exceeds the total value of the Mykolayiv and Kherson regions by 3.4 times.

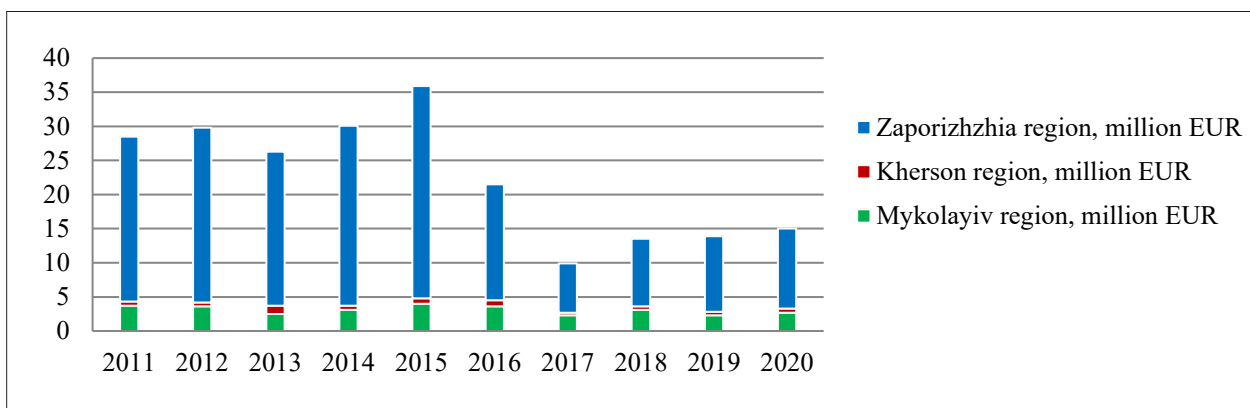


Figure 5. The structure of imports of agri-food products in terms of administrative regions of the Steppe zone of Ukraine for 2011-2020, million EUR

Source: calculated by the authors according to data [32]

It should be noted that the specialization of agri-food production entities in the regions of the Steppe zone is manifested in the commodity structure of foreign trade operations (Fig. 6). Thus, in 2011 there was an increase in exports of live animals and products of animal origin in 2.3 times and products of plant origin – in 2.2 times. However, in 2020, exports of products under the group “Fats and oils of animal or vegetable origin” and “Prepared food products” fluctuated at the level 17.0% and 22.8% respectively. The growth of total agri-food exports in the Steppe zone of Ukraine in 2020 compared to 2016 is less accelerated – only by 24.5%

(82.7% compared to 2011). The reason for this situation is the reduction by 25.2% the share of exports by group of goods “Live animals, products of animal origin”.

The largest share in the structure of agri-food exports of the Steppe zone of Ukraine is provided by the food market of plant products, the average amount of income from which for 2018-2020 amounted to 60.9 million EUR; the group of products “Animal or vegetable fats and oils” and “Prepared food products” provided an average of 11.8 and 7.9 million EUR respectively; export of products “Live animals; products of animal origin” – only 1.5 million EUR, or 1.9% of the total.

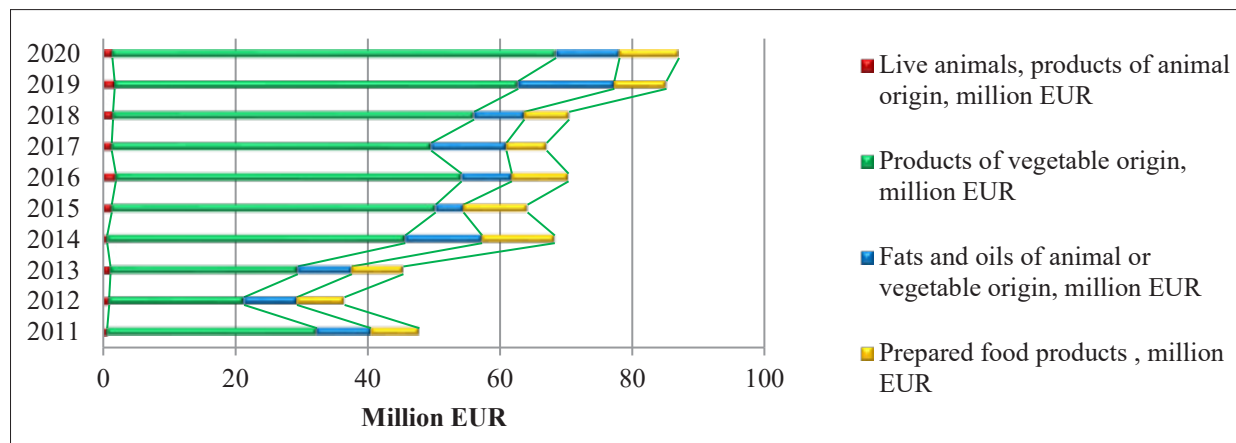


Figure 6. Export of agri-food products of economic entities of the Steppe zone of Ukraine by groups of goods for 2011-2020, million EUR

Source: calculated by the authors according to data [32]

The largest volume of foreign direct investment comes (FDI) to the economy of the Zaporizhzhia region, the amount of which on average for the period 2018-2020 amounted to 111.9 million EUR, which is 5.6-5.8 times higher than their income to the Mykolaiyv and Kherson regions, respectively. At the same time, since 2010 in general in the regions of the Steppe zone there

has been a trend of increasing FDI involvement within 13.7-39.8%. However, in 2020 compared to the level of 2014 there was a tendency to reduce the amount of investment from the world (Virgin Islands, UK, Cyprus, Monaco, the Netherlands, Germany, Panama, Singapore, USA, France, Switzerland) by 19.5%, 18.2% and 27.8% respectively (Fig. 7).

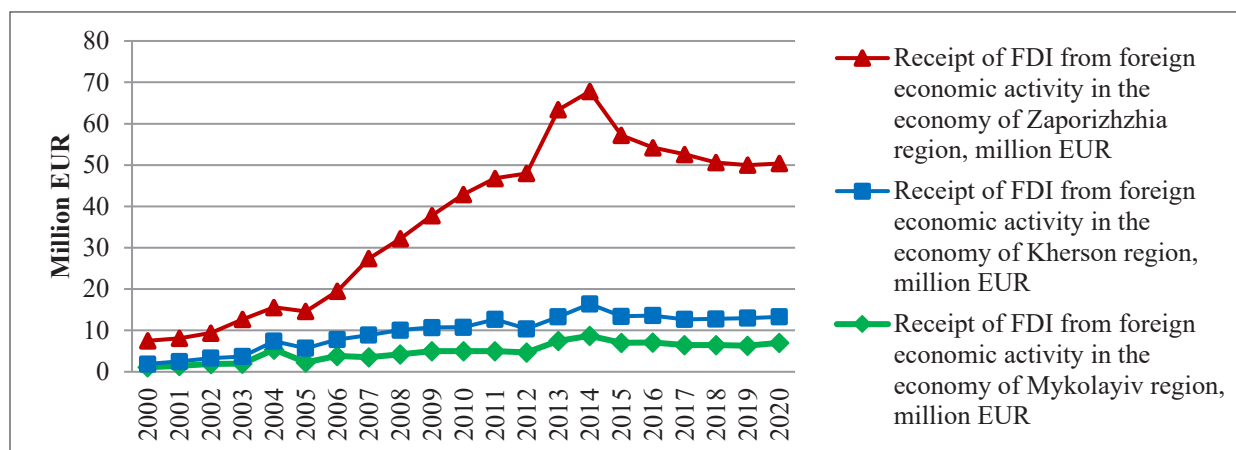


Figure 7. FDI inflows from foreign economic activity of agri-food production entities into the economy of the regions of the Steppe Zone of Ukraine for 2000-2020, million EUR

Source: calculated by the authors according to data [32]

The total amount of attracted foreign direct investment from foreign economic activity in the investment infrastructure of the agri-food production of the Steppe zone is presented in Figure 8.

Sectoral distribution of foreign direct investment from foreign economic activity involved in the infrastructure of agri-food production of the Steppe zone allows to stabilize the production potential and increase the investment attractiveness of agriculture, forestry and fisheries, ensure food, beverage and tobacco production (Fig. 9).

It should be noted that in 2020, the distribution of foreign direct investment at the level of 5.7% provided 0.4 million EUR additional funds for the development of agriculture, forestry and fisheries. The increase in foreign investment in the production of food, beverages and tobacco to 94.3% provided 0.7 million EUR in cash inflows to the Steppe regions. The main investor who invests in the development of agri-food production entities from foreign economic activity is Cyprus, due to preferential taxation.

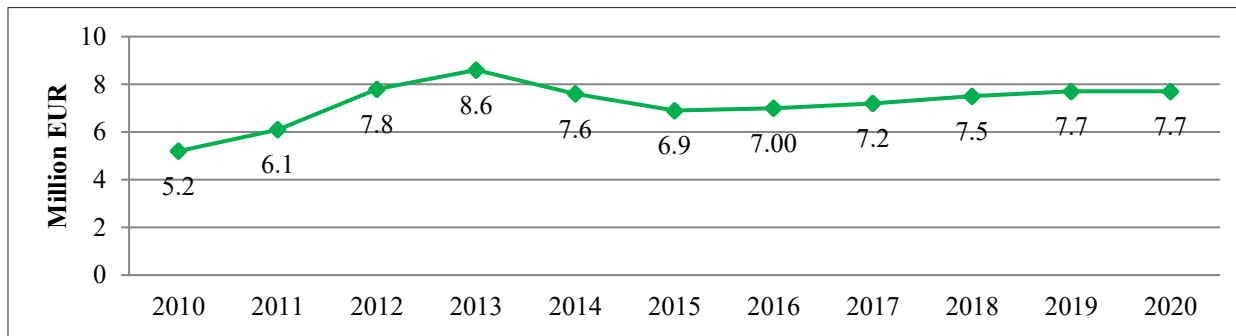


Figure 8. Attracting FDI for the development of investment infrastructure of agri-food production entities of the Steppe zone for 2010-2020, million EUR

Source: calculated by the authors according to data [32]

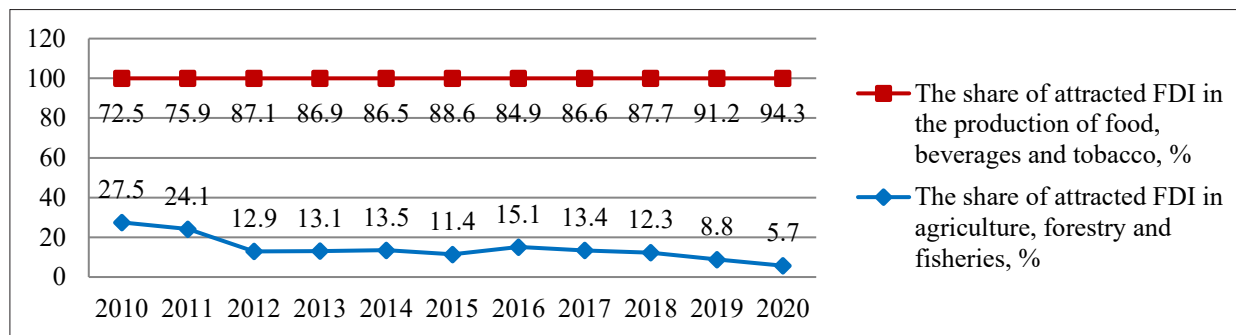


Figure 9. Sectoral distribution of FDI involved in the investment infrastructure of agri-food production of the Steppe zone for 2010-2020, %

Source: calculated by the authors according to data [32]

The geography of sales of agri-food products of the Steppe zone of Ukraine for the last 2010-2020 has significantly expanded in Europe and Asia (Fig. 10-11). Supplies to the Middle East and North Africa are relatively stable; exports to Southeast Asia have increased 8 times in recent years, in the EU – in 13 times. In 2020, compared to 2019, the leaders who increased the supply of Ukrainian food are: Germany, where the increase was

8.2 million EUR, reaching the value of 20.5 million EUR of imports from Ukraine; Saudi Arabia (increase 7.1 million EUR to the amount of 18.1 million EUR); Philippines (increase 5.5 million EUR to the amount of 9.9 million EUR); Iraq (increase 5.2 million EUR to the amount of 10.9 million EUR); Indonesia (increase +5.0 million EUR to the amount of 15.5 million EUR).

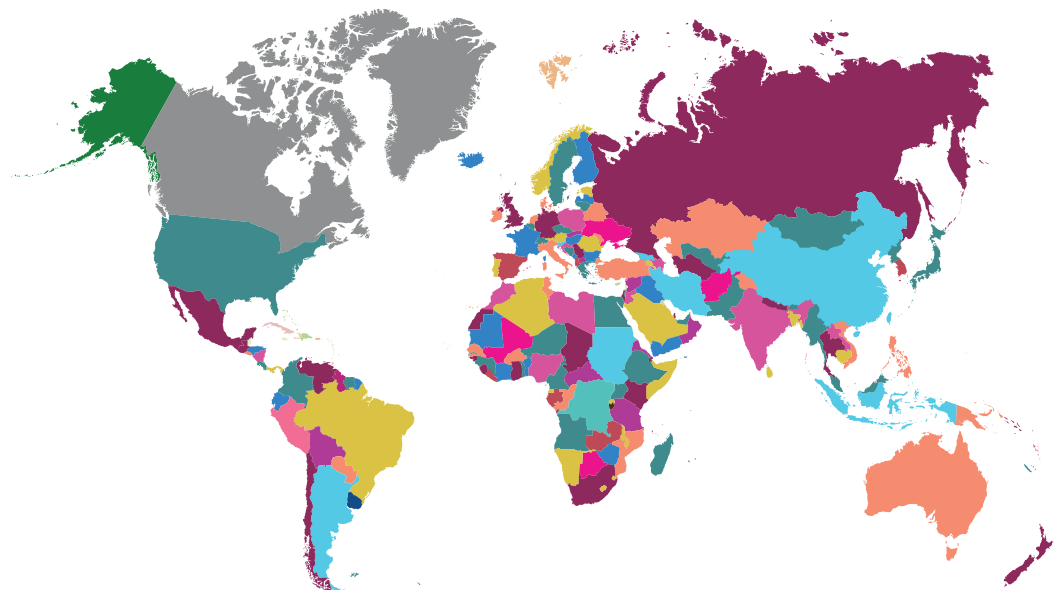


Figure 10. Geography of agri-food exports of the Steppe zone of Ukraine in international trade markets

Source: built by the authors according to data [33]

To predict the size of exports of agri-food products of the studied regions of the Steppe zone, we choose the method of time trend. The solution to the extrapolation problem is to find a dependence $X=f(t)$ that describes with sufficient accuracy the behavior of the variable X in the past and at the same time is also defined for some

time interval in the future. The choice of the type of function is based on a theoretical analysis of the essence of the phenomenon, which studies the nature of its dynamics. Usually, preference is given to functions whose parameters have a clear economic meaning and measure the absolute or relative rate of development.

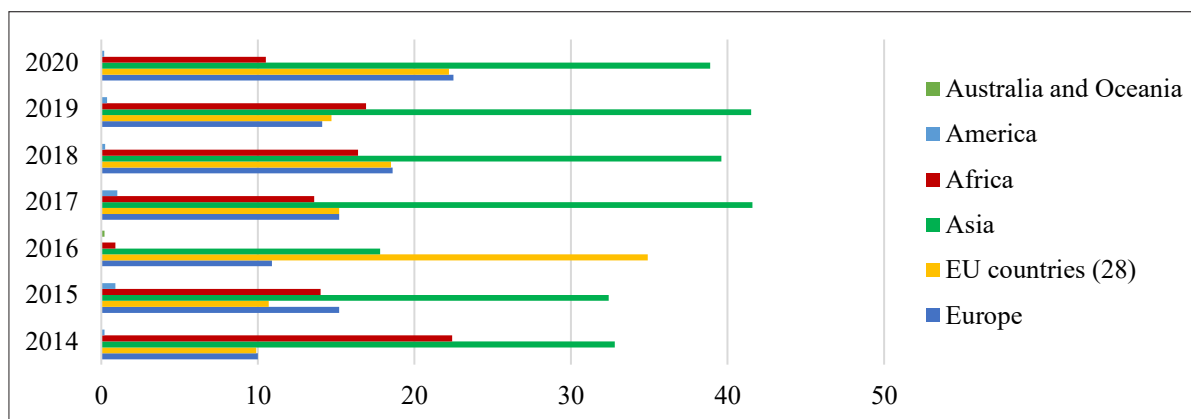


Figure 11. Geographical structure of agri-food exports to one region of the Steppe zone of Ukraine for 2014-2020, %
Source: calculated by the authors according to data [32]

When choosing the functions, the analysis of the chain characteristics of the intensity of dynamics is used. If the chain absolute increments are relatively stable, do not have a clear tendency to increase or decrease, the alignment of the series is performed on the basis of a linear function: $Y_t=a+bt$. If the chain growth rates are relatively stable, then the exponent $Y_t=ab^t$ is the most adequate to this type of dynamics. In these functions t – is the ordinal number of the period (date), and a – is the level of the series at $t=0$. The parameter b

characterizes the rate of dynamics: the average absolute in the linear function and the average relative in the exponent. When the characteristics of the rate of development increase (or decrease), we use other functions (parabola of the 2nd degree, modified exponent, etc.). The projected size of export of production of the entities of agri-food production of the Mykolayiv region of the Steppe zone of Ukraine for 2021-2022 is calculated according to data of (Fig. 9) and (Fig. 12).

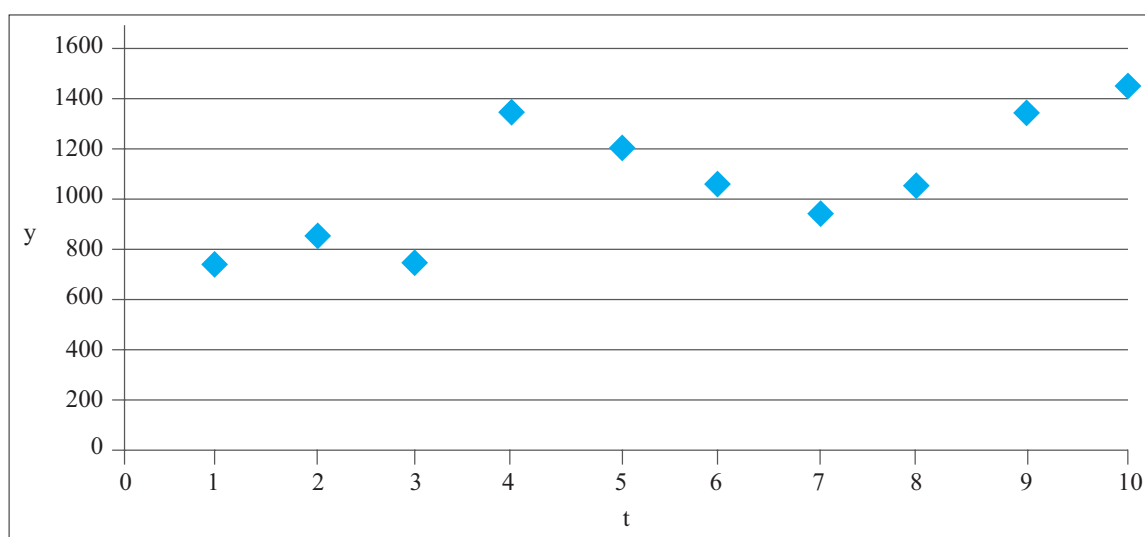


Figure 12. Actual dynamics of export of production of the entities of agri-food production of the Mykolayiv region of the Steppe zone for 2010-2020, thousand EUR ($t=1-10$)

Source: calculated by the authors according to data [32]

The model of the linear trend of export production volume of the entities of agri-food production of the Mykolayiv region is equal $y(t)=733.42+61.72t$, thousand EUR.

Thus, the annual size of exports of agri-food products in the region will increase by an average of 61.72 thousand EUR.

Predicted values:

$$y(2021)=733.42+61.72 \times 11=1412.34 \text{ thousand EUR.}$$

$$y(2022)=733.42+61.72 \times 12=1474.06 \text{ thousand EUR.}$$

The actual dynamics of the size of exports of products of agri-food production for extrapolation forecasting of its volume in the Kherson region of the Steppe zone of Ukraine is shown in Figure 13.

The model of the linear trend of the volume of export of products of agri-food production of the region is equal to $y(t)=172.87+0.8861t$, thousand EUR. Accordingly, the annual export of agri-food products of the region will increase by an average of 0.8861 thousand EUR.

Predicted values:

$$y(2021)=172.87+0.8861 \times 11=182.617 \text{ thousand EUR.}$$

$$y(2022)=172.87+0.8861 \times 12=183.503 \text{ thousand EUR.}$$

The actual dynamics of the size of exports of products of agri-food production for extrapolation forecasting of its volume in the Zaporizhzhia region of the Steppe zone of Ukraine is shown in Figure 14. The model of the linear

trend of the volume of export of products of agri-food production of the region is equal to $y(t)=348.79+95.045t$, thousand EUR. Thus, the annual size of exports of agri-food products in the region will increase by an average of 95.045 thousand EUR.

Predicted values:

$$y(2021)=348.79+95.045 \times 11=1394.285 \text{ thousand EUR.}$$

$$y(2022)=348.79+95.045 \times 12=1489.33 \text{ thousand EUR.}$$

In general, the projected size of exports of agri-food products of the Steppe zone in attracting foreign investment from foreign economic activity in 2021 will provide cash inflows to the economy of the studied regions at 2989.242 thousand EUR, in 2022 – at 3146.893 thousand EUR. However, in order to further intensify foreign economic activity for the development of investment infrastructure of agri-food production entities, the priority is to intensify the export potential of the regions.

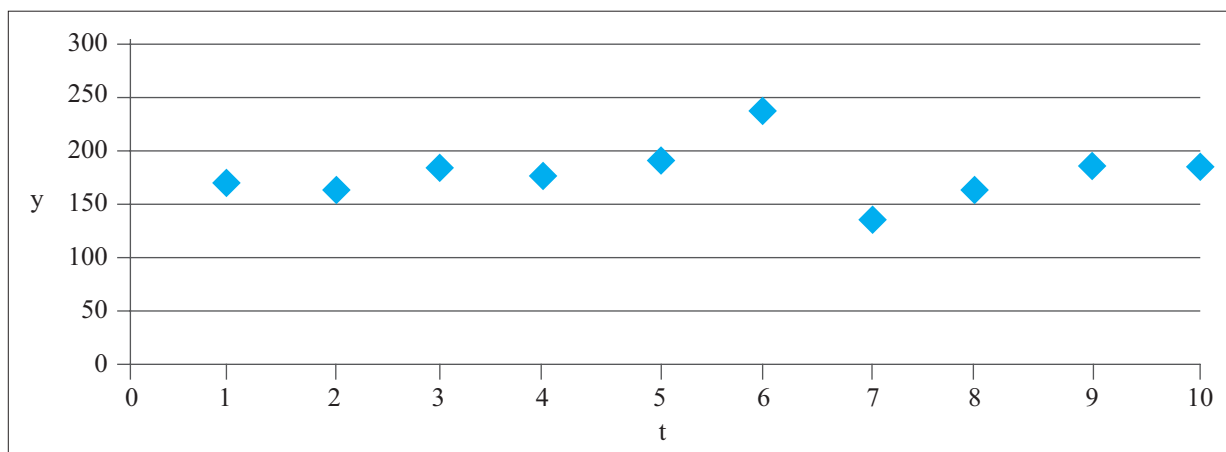


Figure 13. The actual dynamics of exports of products of agri-food production of the Kherson region of the Steppe zone for 2010-2020, thousand EUR ($t=1-10$)

Source: calculated by the authors according to data [32]

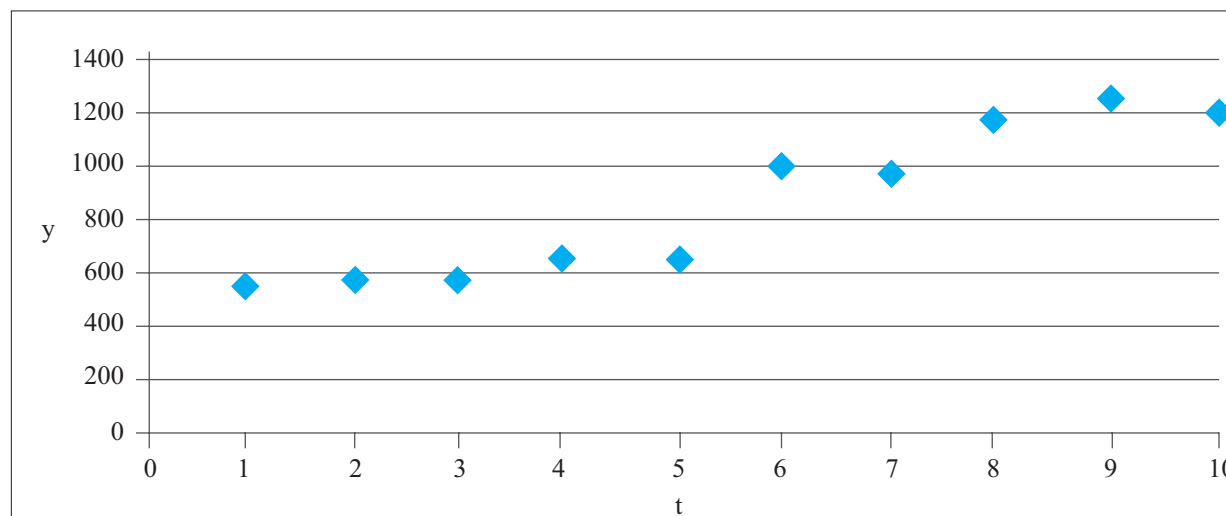


Figure 14. The actual dynamics of exports of agricultural products of the Zaporizhzhia region of the Steppe zone for 2010-2020, thousand EUR ($t=1-10$)

Source: calculated by the authors according to data [32]

According to the developed comprehensive approach to assessing the attractiveness of investment infrastructure of agri-food entities of the Steppe zone, we have calculated four scenarios of threshold parameters

for indicators that enhance foreign economic activity by attracting foreign direct investment to the regions in the short term, i.e., 2021-2022 (Table 2).

Table 2. Forecast parameters of indicators of attractiveness of investment infrastructure of agri-food production entities of the Steppe zone when attracting foreign direct investment from foreign economic activity

Indicators	Forecast	
	2021	2022
Scenario I (Live animals, products of animal origin)		
Gross value added, thousand EUR	34.0	85.5
Efficiency of fixed assets, EUR	0.41	0.62
Net profit, thousand EUR	3.1	11.0
Profitability of production, %	22.1	18.2
Scenario II (Fats and oils of animal or vegetable origin)		
Gross value added, thousand EUR	55.4	67.1
Efficiency of fixed assets, EUR	0.35	0.39
Net profit, thousand EUR	7.1	8.7
Profitability of production, %	15.4	23.8
Scenario III (Products of vegetable origin)		
Gross value added, thousand EUR	369.2	454.5
Efficiency of fixed assets, EUR	1.42	1.65
Net profit, thousand EUR	78.5	121.4
Profitability of production, %	40.3	45.6
Scenario IV (Prepared food products)		
Gross value added, thousand EUR	262.9	358.2
Efficiency of fixed assets, EUR	1.8	1.82
Net profit, thousand EUR	79.0	115.4
Profitability of production, %	56.1	62.2

Source: calculated by the authors

The calculations prove the feasibility of developing the investment infrastructure of agri-food production entities in the Steppe regions and combining them into clusters with processing enterprises, which will improve foreign economic activity and increase the production and export potential of the agricultural sector.

CONCLUSIONS

Thus, the constant development of export capacity is the main condition for the effective operation of economic entities in the dynamic environment of the modern market. At the same time, approaches to the development of export potential reflect different levels: countries, regions, industries and enterprises. Export potential at the level of agri-food production entities, which directly creates material goods, provides conditions for an efficient process of investment operations and enables the

production of competitive products. The processes of export-import operations are closely interconnected and interdependent, resulting in increased efficiency of many financial and economic indicators and profitability. In addition, the level of providing foreign food producers with foreign currency is growing. This, in turn, provides further innovative development through the acquisition of modern technologies and the latest machinery (equipment, machinery, etc.) from foreign partners. Participation in export-import operations creates opportunities to balance the structure and range of exports of agri-food products in the direction of increasing its commodity form instead of materials and raw materials.

However, without significant state support of domestic farmers, the implementation of these intentions is impossible. The mechanism of state support and regulation of domestic producers, including through the

support of export operations, should include the use of various forms, methods and techniques of legal and economic nature. In this case, the state should act as a guarantor of investment security, socio-economic stability for foreign and domestic investors.

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Зовнішньоекономічні пріоритети розвитку інвестиційної інфраструктури суб'єктів агропродовольчого виробництва

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Анотація. У статті розглянуто зовнішньоекономічні пріоритети розвитку інвестиційної інфраструктури суб'єктів агропродовольчого виробництва України. Розроблено комплексний методологічний підхід до оцінки ефективної диверсифікації інвестиційної інфраструктури суб'єктів агропродовольчого виробництва. Обґрунтована діагностика залучення прямих іноземних інвестицій у розвиток агропродовольчого виробництва дозволяє сформувати експортно-орієнтований тип державної економіки, визначити основні джерела технічного оснащення агробізнесу та освоїти інноваційні технології, сформувати виробничий потенціал та механізм реалізації стратегічних інвестиційних цілей. Розроблено алгоритм розрахунку рівня привабливості інвестиційної інфраструктури суб'єктів агропродовольчого виробництва. Наведено динаміку зовнішньої торгівлі агропродовольчими товарами степової зони України. Визначається обсяг прямих іноземних інвестицій від зовнішньоекономічної діяльності суб'єктів агропродовольчого виробництва в економіці регіонів Степової зони України. Представлено географію експорту агропродовольчих товарів степової зони України на міжнародних торгових ринках. Розраховано прогнозний обсяг експорту агропродовольчих товарів у регіонах та визначено граничні параметри показників привабливості інвестиційної інфраструктури суб'єктів при залученні прямих іноземних інвестицій із зовнішньоекономічних операцій

Ключові слова: прями іноземні інвестиції, зовнішньоекономічна діяльність, інвестиційна інфраструктура, суб'єкти агропродовольчого виробництва, експорт, імпорт

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Managing the Potential of Agro-Industrial Enterprises in the Consumer Market

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Abstract. The article implements aspects of managing the potential of agro-industrial enterprises in the consumer market. A comprehensive methodological approach to diagnosing the model of assessing the management of the potential of agro-industrial enterprises is proposed, which on the basis of the mathematical apparatus of fuzzy theories allows to optimize its level in the chain of aggregate components, reduce the pressure of factors to limit the competitive position of businesses in the consumer market. It is proved that economic diagnostics allows to reveal causal relations in managerial dysfunctions and to pass to the model of sustainable development of the enterprise and effective use of its potential. A group (integrated) system of economic system diagnostics is proposed, which combines the properties of traditional "rigid" models and algorithms that assess the state of management of agro-industrial enterprises and the reasons for their dysfunction in many uncontrolled flows of resources, with the probability of failure. It is substantiated that the main component in managing the potential of the enterprise is the availability of potential resources, the totality and interaction of which opens up promising opportunities to achieve management goals. The directions of estimating the value of the potential of the agro-industrial enterprise are determined. An expert assessment of the integrated factor coefficient of economic stability of the potential of agricultural holdings of the meat-processing unit of Ukraine has been carried out. The graph-analytical levels of type manifestations of the potential and the profile of its components at the enterprises of agro-industrial production of meat processing unit are determined. Standardized coefficients for rating of agricultural holdings of the meat-processing unit of Ukraine according to their potential have been calculated. The forecast level of indicators and the integrated coefficient of effective management of the potential of agro-industrial enterprises are established

Keywords: land and resource potential, land relations, rent, yield, cost price, income, profitability



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INTRODUCTION

The challenges of globalization, vertical integration, the pandemic, and the intensification of market competition are becoming more and more tangible for agro-industrial enterprises and put them in a difficult economic situation. Modern economic events and processes carried out in the agro-industrial complex are not within the generally accepted theories, so they need other approaches to the formation of new areas of economic growth with emphasis on improving management efficiency and meeting the needs of the consumer market. In this case, the activities of agro-industrial enterprises will be effective in the case of the correct formation of the composition and structure of their potential, which, in turn, is the object of management, which depends not only on the amount of resources involved but also on their efficiency and interaction. Management decisions cannot be limited to the narrow framework of current production problems, as the activities of enterprises should anticipate changes that occur in the external environment to influence the implementation of goals.

Any enterprise is focused on successful operation in the long run. This creates the need to identify the potential, the direction of its use, adaptation to ever-changing environmental conditions, ensuring overall management efficiency. It is the requirements of the external environment that determine the direction of managing the potential of agro-industrial enterprises as a dynamic system consisting of local potentials: raw materials, production, financial, labor, organizational and managerial, investment, information, infrastructure, marketing, economic potential and domestic and non-production reserves [1]. The main component in managing the potential of the enterprise is the availability of potential resources, the totality and interaction of which opens up promising opportunities to achieve management goals. The resource component is able to contribute in the end to the implementation of the mission chosen by the enterprise and meet the ever-changing needs of potential consumers.

The potential in various aspects and hierarchical levels was studied by O. Hlon, V. Dubovoi [2], O. Moroz, A. Matviichuk [3], S. Ramazanov, V. Pripoten [4], V. Rudashevskiy [5], V. Timofeeva, K. Bushuiev [6], A. Uskov, A. Kuzmin [7], who connected it with the welfare of the society and with the productive potential of the nation. The foundations of the theory of economic potential have been formed by I. Azhaman, O. Zhydkov [8], O. Fedonin, I. Riepina, O. Oleksiuk [9], N. Krasnokutska [10], N. Vashchenko [11]. The structure, relationships of the potential of the enterprise, its competitiveness and management system were studied by I. Simenko, M. Romaniuk [12], R. Grant [13], R. Makadok [14], E. Penrose [15], R. Amit, P.J. Shoemaker [16], A. Voronkova [17]. Paying tribute to previous scientific achievements, there is a need for a systematic study of the potential of agro-industrial enterprises in the context of identifying its structure and components, creating an intelligent system of automated

management of business tools given the need to use potential reserves and their ability to provide resource structure of the potential in the consumer market. The priority of study is to diagnose the model of assessing the management potential of agro-industrial enterprises, which based on the mathematical apparatus of fuzzy theories allows to optimize its level in the chain of aggregate components, reduce the pressure of factors limiting the competitive position of businesses in the consumer market.

MATERIALS AND METHODS

The potential of agro-industrial enterprises has a high ability to adapt to changing environmental conditions, due to: 1) constant monitoring of changing needs and demand for goods and services, promotion and implementation of competitive ideas that best meet these needs and demand; 2) adaptation of the production apparatus to the most effective performance of its functions by the enterprise. The extreme complexity is the assessment of the degree of adaptability of the potential of the enterprise, as it is determined not only by internal but also external influences. First, such influence arises from the demand on the production of the enterprise. The variability of demand parameters is due to a set of reasons of economic, political, demographic and socio-cultural nature. The adaptability of the potential of the enterprise is also influenced by the situation in the markets of material resources, financial markets, labor markets, information and services [18; 19]. This means that, like any system, the potential of the enterprise has the ultimate ability to adapt to ever-changing production conditions and requires minimization of the negative consequences of changes that occur, as well as factors of "uncertainty of the future" [20]. This determines the need to diagnose capacity as an economic system (ES), which begins with the analysis, including the external and internal environment of competitors, suppliers, customers, human resources, financial, labor and technical resources of the enterprise.

Economic diagnostics allows identifying causal links in management dysfunction and moving to a model of sustainable development of the enterprise and the effective use of its potential. Diagnosis is considered as a reflective management technology, which in the early stages of crisis development is the methodological basis of the model that connects modern management and the dynamic economic reality of the enterprise [21]. Diagnosis allows to determine the state of the functioning of the control object (evaluation function); identify possible changes in the state of the object (diagnostic function) and anticipate possible measures to improve or restore the state of the control entity (search function) [22]. The objects of agro-industrial production belong to the class of complex economic systems (ES), which in the process of their purposeful or given functioning are in dynamics

and prone to both controlled and uncontrolled actions. That is, the state of ES of enterprises over time undergoes certain changes.

The group (integrated) system (GIS) of the diagnostics of (ES) is offered, combining properties of the traditional "rigid" models and algorithms which estimate a condition of management of potential of the enterprises of agro-industrial production and the reasons of disturbance of their functioning in set of uncontrolled streams of resources with the probability of not obtaining an effective result of their action. However, the lack of sufficient statistics to establish objective relationships between the values of probabilistic diagnoses determines the heuristic description of these relationships. In general, the model of the diagnostic object and information transmission channels can be represented as the following equations [23; 24]:

$$F(x, u, a, t) = 0, y(t) = G(x, u, \xi_0, v, b, t) \quad (1)$$

where $x \in R^n$ – is the state vector; $u \in R^r$ – control vector; $y \in R^m$ – vector of output variables; w, v – vectors of perturbations and obstacles (included in equations (2-4) both additively and multiplicatively); a, b – vectors of indeterminate parameters, and $a(t)=0, b(t)=0$; F, G – some given operators (differential, both ordinary and with partial derivatives, integral, integro-differential, matrix and the like).

If the potential of the ES consists of N resources (elements) and each element is associated with other $(N-1)$ elements (integral potential of the ES), then the maximum possible number of connections between resources (elements) will look like [23; 24]:

$$M_{max} = N(N - 1) \quad (2)$$

If the number of actual connections (M_f) is less than the maximum possible (not every element is connected with all other elements), then the degree of integrity (I_{ntg}) of the ES potential will be determined by the formula (3) [23; 24]:

$$I_{ntg} = M_f / M_{max} \quad (3)$$

Should note, when $M_f = M_{max}, I_{ntg} = 1$, i.e., ES is integral; when $M_f = 0, I_{ntg} = 0$ – the potential of the ES is isolated.

The degree of isolation (I_{isol}) of the potential can be determined by the formula (4) [23; 24]:

$$I_{isol} = 1 - I_{ntg} \quad (4)$$

In this case, if $I_{ntg} = 1$, then $I_{isol} = 0$; if $I_{ntg} = 0$, then $I_{isol} = 1$. Thus, the potential of the ES combines the properties of integrity and isolation ($I_{ntg} \leq 1.0$; $I_{isol} \leq 1$). The rational combination of the properties of integrity and isolation determines the possibilities of developing the potential of the ES through its modernization. Increasing the integrity of the ES potential contributes to its efficiency, but increases the complexity of the system, which, in turn, increases the need for resources needed to create and operate the system. The more isolated the

system, the more flexible and less complex it is. However, increasing the degree of isolation, as a rule, reduces the effectiveness of the potential of the ES. All elements that demonstrate a high enough closeness of communication with each other and provide a certain functioning combination with other elements can be attributed to the components of the potential of the ES, and all other elements – to the elements of its external environment. It is not necessary to reduce the formation and development of the potential of the enterprise's ES only to the formation and development of its elements.

The combined functioning of heterogeneous interdependent components of the potential generates qualitatively new functional properties of the whole, which has no analogues in the properties of its components.

In particular, stochastic differential equations (linear or nonlinear, continuous or discrete), partial derivative equations can be used as model (1), for example, for cases of accounting for the territorial location of production facilities. Models for processing and identification that can be practically implemented have the following form [23; 24]:

$$\dot{x}(t) = A(t, \theta)x + B(t, \theta)u + W(t), y(t) = C(t, \theta) \quad (5)$$

or, in the discrete case:

$$y(k + 1) = H(k)x(k) + V(k) \quad (6)$$

$$x(k + 1) = \hat{O}(k + 1, k, \theta)x + \psi(k + 1, k)u(k) + W(k) \quad (7)$$

The control condition (scheme) of diagnosis is usually a relationship of the type [25]:

$$\mu(E(t)) \leq \delta \quad (8)$$

where $\mu(\cdot)$ – some given metric, for example, the Euclidean norm; $u \in R^r$ – control vector; δ – the allowable threshold value that is set; $E(t)$ – non-viscous (deviation) or deviation from the norm, or assessment of the state from the standard, or assessment of parameters from the nominal, or characteristics of estimates from the possible (for example, covariance of renewal processes in the Kalman filter). For example:

$$E(t) = \hat{O}(y^F, q^{-1}y^F, \dots, q^{-k}y^F, u^F, q^{-1}u^F, \dots, q^{-k}u^F) \quad (9)$$

where F – operator; k – the order of the control scheme to be determined (or assigned). Then, provided there is no error (flaws) $E(t)$ will look like: $E(t)=0, t=0, 1, 2, \dots$ and equation (8) will look like this: $\|E(t)\| \leq \delta$. We note that the problem can be solved both in the case of deterministic and in conditions of stochastic and multiple uncertainty.

To increase the efficiency and quality of diagnosing the complex ES, which include agro-industrial enterprises, it is necessary to use the subjective probability of diagnoses from a predetermined number of diagnoses D_1, \dots, D_k . Each of $X_i, i=(\overline{1, \dots, n})$, acquires a value from the set $X = \{x_{i1}, \dots, x_{im}, \dots, x_{ip}\}$. At time t , the state of the object is described by a feature vector [26]:

$$X(t) = [X_1(t), \dots, X_n(t)] X_i(t) = X_{im}]^F, m_i = \overline{1, p_i} \quad (10)$$

where $X_1(t)$ – is the realization of the sign X_i at the present moment t .

There is a need to determine the assessment of the probability (measure of possibility) of economic diagnosis $P_\sigma(j)$ [26]:

$$\forall j = \overline{1, k}: \hat{O}_a(j) = \hat{O}_a(D_j/X(t)) \quad (11)$$

where P_σ – is a symbol of subjective probability.

To solve this problem, the representation of expert knowledge in linguistic form is used. In this case, the expert operates fuzzy categories, such as: "If the value X_i is very large, the probability D_j – is small". Therefore, a linguistic approach based on fuzzy set theory can be applied to the modeling of fuzzy information [26]. In the fuzzy algorithm of diagnosing the sign and probability are represented by linguistic variables (LV), defined by formula (12-13) [26]:

$$(X_i, T_i, V_i, G_i, M_i), i = 1, n \quad (12)$$

$$(P_a, P, U, S, Q) \quad (13)$$

where P_a, X_i – the names of the corresponding LV, T_i, P – the term set of variables X_i and P_σ respectively, i.e., many of their linguistic meanings, which is the name of fuzzy variables (FV) [26]:

$$A_{if}(f_i = \overline{1, p_i}/p_i = cardT_i) \text{ and } B_r(r = \overline{1, m}/m = cardP) \quad (14)$$

with values from universal sets V_i and U ; G_i and S – syntactic rules that generate names A_{if} and B_r of the values of variables X_i and P_σ ; M_p, Q – semantic rules that allow to convert (FV) to each new meaning. Accordingly, the new value A_{if} and B_r has the form (formulas (15-16) [26]:

$$(A_{if}, V_i, \tilde{C}_{if}), i = \overline{1, n} \quad (15)$$

$$(B_r, U, \tilde{E}_r), r = \overline{1, m} \quad (16)$$

where A_{if}, B_r – names of $FV; V_i, U$ – the same as above.

$$\tilde{C}_{if} = \bigcup_{v \in V_i} \mu_{\tilde{C}}(V) / V \text{ and } \tilde{E}_{if} = \bigcup_{v \in U} \mu_{\tilde{E}}(U) / U \quad (17)$$

Fuzzy subsets (FV) of sets V_i and U , describing restrictions on possible values A_{if} and B_r ; $\mu_{\tilde{C}}(\cdot)$ and $\mu_{\tilde{E}}(\cdot)$ – are membership functions (MF) for \tilde{C}_{if} and \tilde{E}_r . For

example, for some block of ES of enterprises with a diagnostic feature $\{X_1, X_2, X_3, X_4, X_5\}$ the following values LV are matched [26]:

$$(X_1, T_1, [" - "], G_1, M_1) \quad (18)$$

$$(X_2, T_2, [" - "], G_2, M_2) \quad (19)$$

$$(X_2, T_5, [" - "], G_5, M_5) \quad (20)$$

where term-sets $T_1 = \dots = T_5 = \{\text{significantly increased, increased, slightly increased, slightly decreased, decreased, significantly decreased, not changed}\}$.

Probability estimation is represented by the eponymous P_σ , and the term set P consists of the following linguistic values of the variable: B_1 – excluded, B_2 – almost unbelievable, B_3 – very unlikely, B_4 – unlikely ..., B_m – absolutely accurate. Based on a set of rules, a matrix of fuzzy relations is built [26]:

$$X_j, RD_j, \text{ or } R = \bigcup_{x \in X \in D} \mu_R(x, d) / (x, d) \quad (21)$$

RESULTS

The management of the potential of agro-industrial enterprises is dominated by the cost approach, which is associated with the development of long-term and current operational solutions aimed at generating revenue and maximizing the value of the potential of agro-industrial entities [27]. The growth of the value of the potential of the enterprise is an indicator of evaluating the effectiveness of management staff and serves as a generalizing indicator of management, shows the vector of its future development in the system of modern evaluation coordinates. From the methodological point of view, there are two interrelated, but not identical areas of assessing the value of the potential of agro-industrial enterprises (Fig. 1). The first direction is formed in order to establish the balance and market value of competitive potential using standards for valuation of property and business. The assessment is based on three approaches: property (cost), comparison (market) and income (performance).

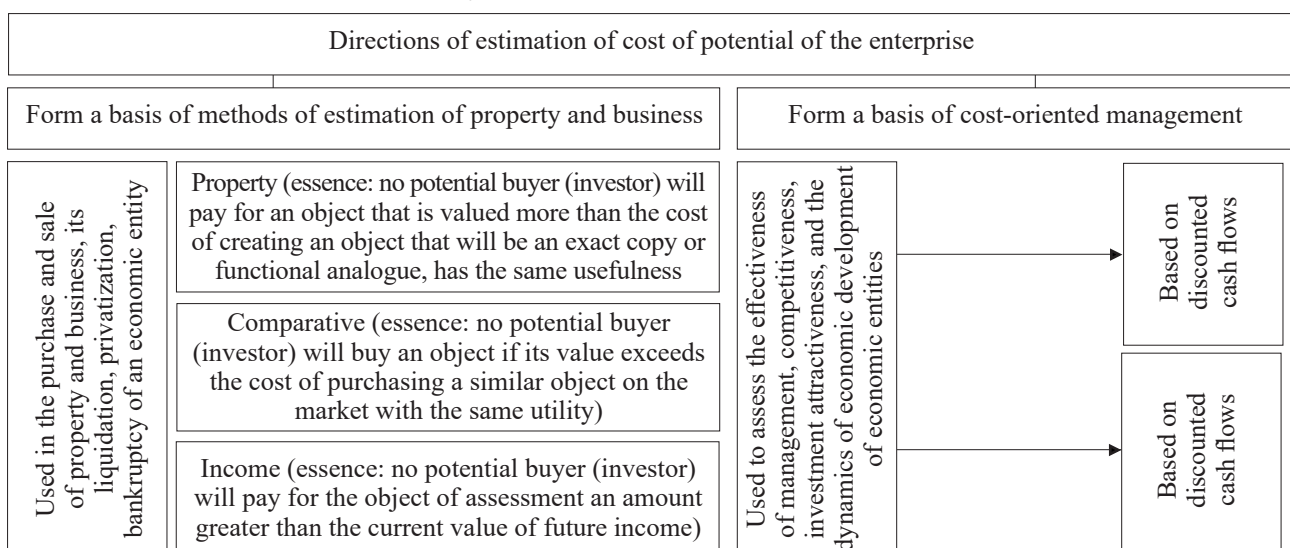


Figure 1. Directions of assessing the value of the potential of agro-industrial enterprises

Source: compiled by the authors based on [27]

We describe in more detail the use of performance (income) approach, which is characterized by two methods: a) direct capitalization of income; b) discounting cash flows (not direct capitalization). The direct capitalization method is used in the case of forecasting a constant value

and equal in time intervals net operating income [27; 28]. The sequence of using the method of direct capitalization of income for the valuation of movable and immovable property has successive stages of determining the value (Fig. 2).

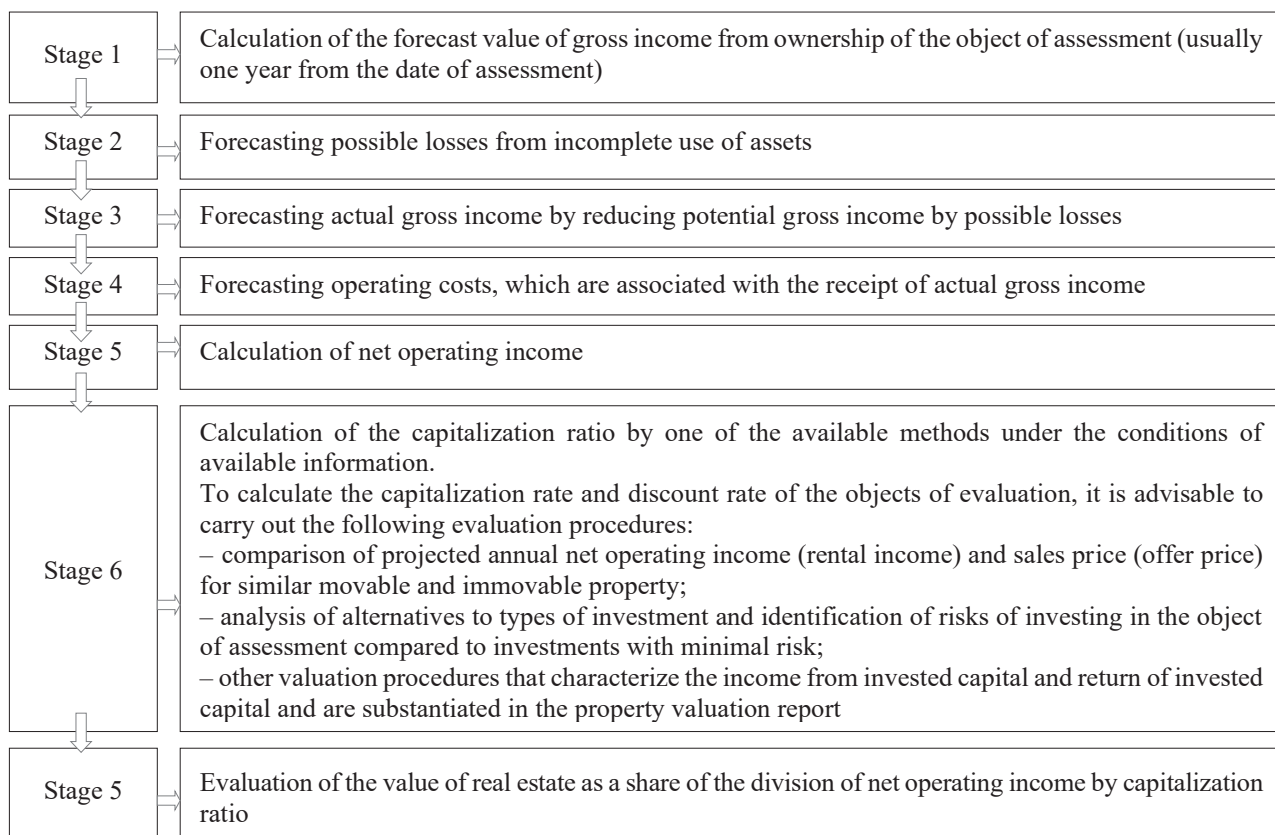


Figure 2. The sequence of using the method of direct capitalization of income for the valuation of movable and immovable property

Source: improved by the authors based on data [28; 29]

Projected net operating income that generates potential is different in value, volatile in revenue over a given forecasting period over time. In this case, the cost of reversion (income from resale – C_{rev}) implies that the potential in the forecast period is able to generate income, i.e., to have a stable growth rate, or uniform cash income. The cost of reversion is determined by formula (22) [28; 29]:

$$C_{rev} = \frac{NCF(t+1)}{(i - l_t)} \quad (22)$$

where C_{rev} – the cost of reversion; $NCF(t+1)$ – net cash flow of income for the first year of the post-forecast period; i – discount rate; l_t – long-term growth rate of cash flow.

In general, the estimate of the value of potential is determined by the sum of the current value of cash flow and the current value of reversal according to formula (23) [28; 29]:

$$C_{cp} = \sum_{i=1}^n \frac{Inc_i}{(1+i)} + \frac{CV_{rev}}{i} \quad (23)$$

where C_{cp} – the cost of competitive potential; Inc_i – the expected income from the possession of competitive

potential for the i -th year; CV_{rev} – the current cost of reversion.

A methodical approach to establishing the value and usefulness of the potential based on the net present value (NPV) is proposed. It reflects the increase in the value of the enterprise as a result of the use of potential and is the difference between the amount of cash flows (revenues) arising from the economic system (ES), discounted to their present value and the sum of the discounted value of all cash outflows [28; 29]. To calculate this indicator, formula (24) is used [29]:

$$NPV = \sum_{r=1}^n \frac{Pr_r - C_r}{(1+i)^r} \quad (24)$$

where Pr_1 – full benefits for the year t ; C_t – full costs for the year t ; t – the corresponding year of the project (1, 2, 3, ... n); n – the term of use of the potential, the depth of the horizon in years; i – discount rate (interest).

$$NPV = \frac{Pr_1 - C_1}{(1+i)^1} + \frac{Pr_2 - C_2}{(1+i)^2} + \dots + \frac{Pr_n - C_n}{(1+i)^n} \quad (25)$$

$$NPV = \sum_{r=1}^n \frac{Pr_1}{(1+i)^t} - \sum_{r=1}^n \frac{C_t}{(1+i)^t} \quad (26)$$

In cases where the option of the potential growth involves significant initial investment I_0 in resources, the calculation NPV is carried out according to formula (27) [29]:

$$NPV = \frac{CF_1}{(1+i)^1} + \frac{CF_2}{(1+i)^2} + \dots + \frac{CF_n}{(1+i)^n} - I_0 = -I_0 + \sum_{t=1}^n \frac{CF_t}{(1+i)^t} \quad (27)$$

where CF_t (cash flow) – cash flow at the end of period t .

The criterion of selection at net present value means that the usefulness and value of the potential are approved in the case of a positive value NPV , (i.e., due to the realization of the potential, the value of the enterprise will increase). When choosing options to increase the magnitude of the potential, preference is given to those of them who have higher values of net present value.

The spread of the method of valuation of the degree of increase in the value of potential is due to the ability to directly determine the effect. In addition, it allows to estimate the total net benefits from several potential options (the property of additivity is given only to the indicator of net present value). However, this indicator does not reflect the relative degree of value increase, the general criterion that can be used in the practice of management decisions is the coefficient of benefit – cost (benefit cost – B/C). It is defined as the amount of discounted benefits divided by the amount of discounted costs, and is calculated by formula (28) [29]:

$$B/C = \frac{\sum_{t=1}^n B_t / (1+i)^t}{\sum_{t=1}^n C_t / (1+i)^t} \quad (28)$$

The criterion for selecting a variant using the cost-benefit ratio may be its value greater than or equal to one. That is, such a potential is appropriate for use. But if the coefficients of benefit – the costs that meet the established requirements of two or more, then there are difficulties in reasoning the ranking of options. Next, because the relative values of the cost-benefit ratios are compared, they do not reflect the value of the net benefits of using the potential. Thus, the cost-benefit ratio may be higher in an enterprise with a smaller absolute potential. Therefore, it is proposed to use additional calculations of the criterion NPV so as not to make the wrong decision of the choice in choosing the best option.

Given that the enterprise has limited capital, it is necessary to correlate the net benefit with the cost of available capital (formula (29)) [29]:

$$B/C = \frac{\sum_{t=1}^n (B_t - PC_t) / (1+i)^t}{\sum_{t=1}^n C_c / (1+i)^t} \quad (29)$$

where PC – production and operating costs; C_c – capital costs.

In the presence of such a coefficient, the ranking of variants is carried out according to the largest value

of the coefficient (B/C) relative to the value (PC). In addition, when there is a shortage of resources, the cost-benefit ratio is also modified and calculated by formula (30) [29]:

$$B/C = \frac{\sum_{t=1}^n (B_t - C_t) / (1+i)^t}{\sum_{t=1}^n R_t / (1+i)^t} \quad (30)$$

where R_t – the cost of the scarce resource.

Comparing the value of net benefits with the cost of scarce resources, you can select the option of using the potential for which unique resources are significant. Thus, for enterprises of agro-industrial production the scarce resources include foreign currency, which is a stimulating factor of development. In this case, the calculation of the ratio is equal to the ratio of net discounted costs to foreign currency costs. Discounted cash flow takes into account the long-term prospects of the enterprise and the use of its potential. However, sometimes there is a loss of usefulness for the current assessment of activities, i.e., tactical management. Therefore, preference is given to models of “economic Value Added” (EVA), which allows to assess the effectiveness of management decisions. The indicator is an alternative to the traditional EVA analysis. This means that only a management decision that provides a greater return on potential will be effective. Comparing the rate of return on invested capital with the weighted average cost of capital allows to get the value (pre-yield), which measures the level of economic profit, while EVA reflects the absolute value of economic profit. The positive absolute value of the indicator EVA and its positive dynamics indicates an increase in the value of the enterprise, i.e., the value of the potential.

In modern market conditions, an important condition for the functioning of the enterprise is to ensure economic stability and efficiency of its economic system, which is characterized by the orderliness of technical, economic, environmental, social and scientific resources. The economic stability of the potential of agro-industrial enterprises primarily depends on: the stability of production and marketing activities – the optimal range in terms of compliance with market demands, advertising, flexibility of partnerships, reliability of supply logistics; financial activity – profitability of products, absolute liquidity ratio, receivables, net profit (loss); labor activity – the number of staff, labor productivity, labor capital, staff qualifications; innovation activity – use of modern technologies, level of readiness of personnel for changes at the enterprise, level of conformity of organizational culture to innovative development of the enterprise, environmental friendliness of technologies and equipment; management activities – business qualities of employees in the field of management, the effectiveness of the organizational structure of management, the creativity of management staff.

While diagnosing the potential of agro-industrial enterprises, it should be noted that one of the directions

of its evaluation is expertising. Eight agricultural holdings of Ukraine are included in the objects of assessment of the potential of the sample of meat processing enterprises. An integrated (group) factor indicator of enterprises has been formed, which is calculated as the product of a parametric unit assessment and the rank of the analyzed synthesizing factor of a meat processing enterprise (agro-holding). The total assessment consists of integrated (group) factor components of the potential for each of the analyzed enterprises. The coefficient of economic stability potential (FP_s) is taken as a unit for the enterprise that has the highest total score for all components of the potential. For the rest of the enterprises, it is calculated by the ratio to the highest level of the total score of the leading enterprise [30]. Indicators of the integrated factor, which includes production, marketing, management, labor, financial and innovation potential have been se-

lected. The graphic representation of the potentials is divided into two groups of agricultural holdings: those that are only meat processing with the purchase of raw materials and those that are agro-industrial enterprises with their own raw materials. Each agricultural holding corresponds to a polygon with the corresponding calculation of its area S_i by formula (31) [30]:

$$SS_i = \sum_{i=1}^{10} \frac{1}{2} \sin \Delta \times a_i \times a_{i+1} \quad (31)$$

where a_i – is the value of the i -th integrated factor indicator at each of the eight meat products enterprises of agro-industrial production (agroholdings), with $i=8$ (eight integrated factors of the enterprise potential). The area of the polygon of agro-industrial enterprises (agroholdings) is calculated as follows:

$$SS_{ag1} = 1/2 \times 0.71 \times (0.67 \times 0.4 + 0.4 \times 0.58 + 0.58 \times 0.52 + 0.52 \times 0.45 + 0.45 \times 0.4 + 0.46 \times 0.67) = 0.55$$

$$SS_{ag2} = 1/2 \times 0.71 \times (0.68 \times 0.42 + 0.42 \times 0.5 + 0.5 \times 0.53 + 0.53 \times 0.52 + 0.52 \times 0.48 + 0.48 \times 0.68) = 0.57$$

$$SS_{ag3} = 1/2 \times 0.71 \times (0.61 \times 0.36 + 0.36 \times 0.53 + 0.53 \times 0.52 + 0.52 \times 0.46 + 0.46 \times 0.43 + 0.43 \times 0.61) = 0.49$$

$$SS_{ag4} = 1/2 \times 0.71 \times (0.68 \times 0.37 + 0.37 \times 0.48 + 0.48 \times 0.55 + 0.55 \times 0.44 + 0.44 \times 0.49 + 0.49 \times 0.68) = 0.53$$

$$SS_{ag5} = 1/2 \times 0.71 \times (0.65 \times 0.38 + 0.38 \times 0.56 + 0.56 \times 0.56 + 0.56 \times 0.43 + 0.43 \times 0.42 + 0.42 \times 0.65) = 0.52$$

$$SS_{ag6} = 1/2 \times 0.71 \times (0.67 \times 0.37 + 0.37 \times 0.51 + 0.51 \times 0.55 + 0.55 \times 0.46 + 0.46 \times 0.42 + 0.42 \times 0.67) = 0.51$$

$$SS_{ag7} = 1/2 \times 0.71 \times (0.63 \times 0.39 + 0.39 \times 0.56 + 0.56 \times 0.53 + 0.53 \times 0.44 + 0.44 \times 0.46 + 0.46 \times 0.63) = 0.53$$

$$SS_{ag8} = 1/2 \times 0.71 \times (0.65 \times 0.41 + 0.41 \times 0.51 + 0.51 \times 0.56 + 0.56 \times 0.5 + 0.5 \times 0.46 + 0.46 \times 0.65) = 0.55$$

Parametric results of expert assessment of the integrated factor indicator of economic stability of the potential of agricultural holdings of the meat-processing unit are presented in Figure 3.

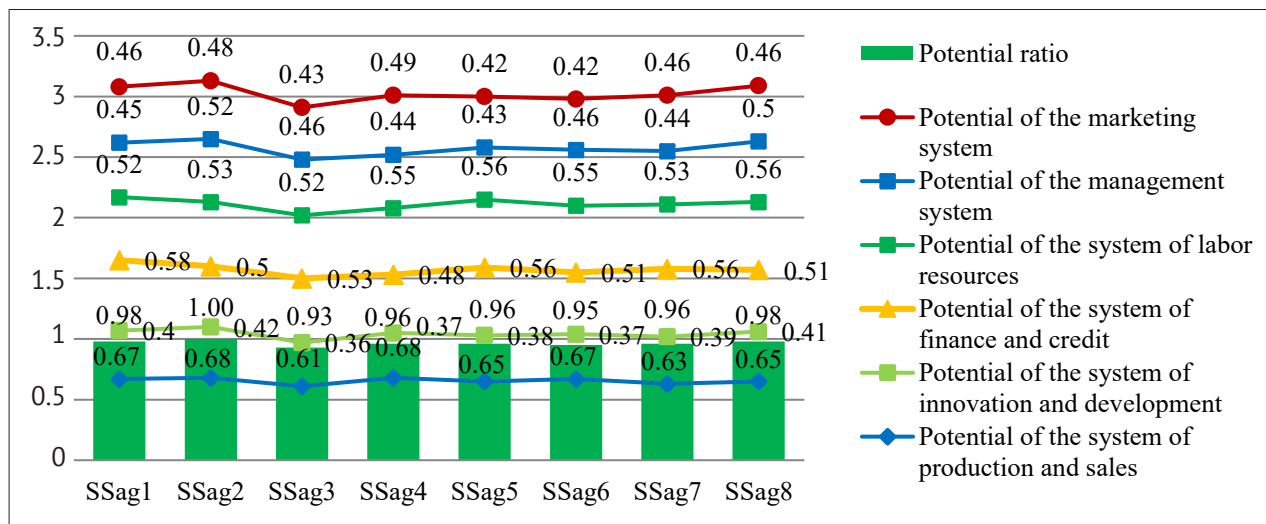


Figure 3. Integral factor coefficient of economic stability of the potential of agricultural holdings of the meat-processing unit, 2020

Source: calculated by the authors

Inaccuracies that arise because of calculations by this method are compensated by the ability to compare graph-analytical and analytical assessment of the

economic stability of the potential of the studied enterprises and identify their place in the level of economic stability of the ES (Table 1).

Table 1. Comparison of levels of economic stability of the potential of agricultural holdings of meat-processing unit by different methods of determination

Agroholdings (meat-processing unit)	Assessment methods			
	Area of potential polygon		Normalized integral coefficient	
	Rank correlation coefficient	Rang	Value	Rang
Agroholding No. 1	0.546	3	0.980	3
Agroholding No. 2	0.520	6	0.958	6
Agroholding No. 3	0.572	1	1.0	1
Agroholding No. 4	0.554	2	0.985	2
Agroholding No. 5	0.512	7	0.951	7
Agroholding No. 6	0.527	5	0.961	5
Agroholding No. 7	0.528	4	0.963	4
Agroholding No. 8	0.492	8	0.931	8

Source: calculated by the authors

The rank correlation coefficient allowed establishing the relationship between the ranked distribution of potentials of the studied agroholdings, which indicates their functionality in the market environment and the high level of economic stability of the potential of the economic system as a whole. Agroholdings are divided into three groups: the first group – enterprises that have the highest level of economic stability (these are agroholdings No. 3, No. 4, No. 1); the second group – enterprises with an average level of economic stability of potential (these are agroholdings No. 2, No. 7, No. 6); the third is enterprises that have a low level of economic stability of potential (these are agroholdings No. 5, No. 8). Monitoring the current capabilities of the components of the potential of agroholdings involves a systematic analysis of the level and effectiveness of the factors that shape them. One of such directions of monitoring is the graph

analytical method of object profile formation. The profile is defined as a graphical representation of selected indicators according to certain principles. The enterprise profile is used to assess the level of potential development by comparing the profiles of competing enterprises built on one evaluation field [31].

Thus, the meat-processing unit of the studied agroholdings may worsen the economic sustainability of economic results not only due to the shortage of certain resources, but also due to their nominal potential. Graph analytical study of the level of use of the components of the potential of meat-processing enterprises showed that for each unit of use of production potential, they spend much more resources and opportunities for management, marketing and innovation potential and small amounts of financial and labor resources Figure 4.

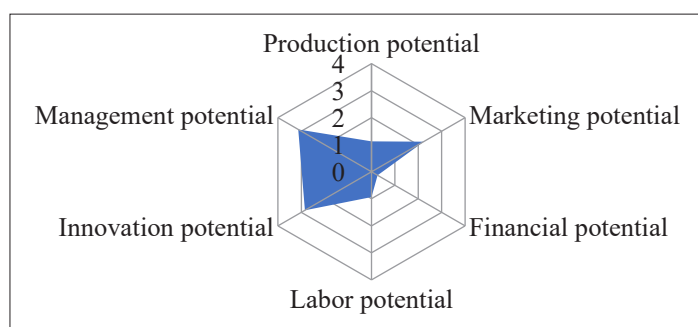


Figure 4. Graph analytical levels of type manifestations of the potential of agroholdings of the meat-processing unit, 2020

Source: calculated by the authors

The selected agroholdings of the meat-processing unit meet the following criteria: the assortment structure of trade turnover, the breadth and depth of the product range are identical; the life cycle phase of the entity and the main strategic development goals;

use of one-way channels of distribution and sale of products; availability of equal opportunities for resource potential formation. It should be noted that the return on equity is an important indicator of investment potential of enterprises, which regulates the redistribution of cash

flows between production and financial potentials, given the profitability of the economic system as a whole. So, the coefficient of stability of economic growth, which remains with the business entity for its development and creation of a reserve, according to Figure. 3 had the largest amount of equity in 2020 (almost 44%) in the agroholding No. 8 and No. 1 – almost 34%, the smallest

one is in the agroholding No. 6 – 0.5%. Meat-processing enterprises No. 2, No. 3, No. 5 did not direct their own capital at all to increase their potential, which reduced their competitive position in the con-ssumer market. The financial component of the potential of agroholdings of the meat-processing unit of Ukraine is presented in Figure 5.

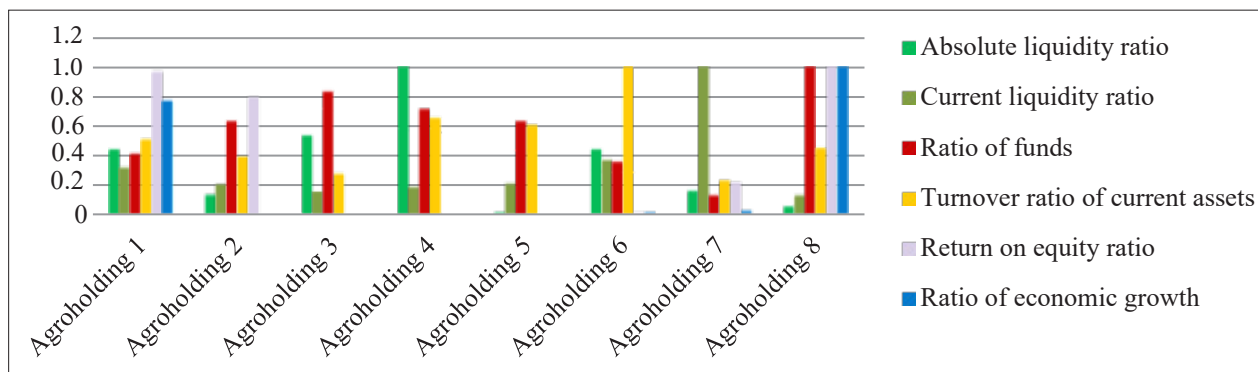


Figure 5. Standardized coefficients for rating of agroholdings of meat-processing unit of Ukraine according to their potential, 2020

Source: calculated by the authors according to data State Statistics Service of Ukraine, 2021 [32]

All elements of standardized coefficients are squared. The obtained results are added in rows, the square root is determined from the obtained sum. Meat-processing enterprises, which had negative coefficients of return on assets and of stable economic

growth were not taken into account, i.e., had zero value. Ratings of potential competitiveness according to the indicators of stable financial condition of agroholdings of meat-processing units are placed in ascending order, due to their economic content Figure 6.

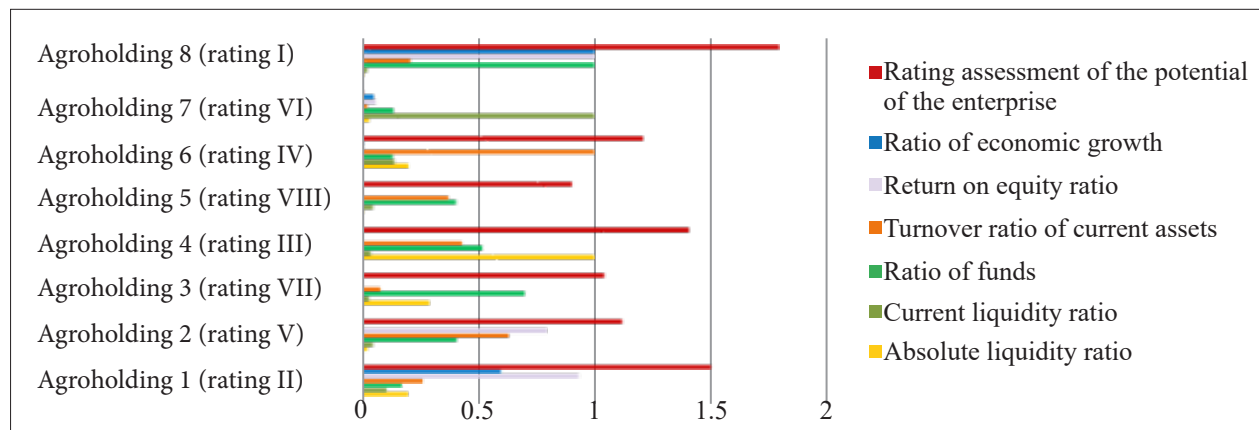


Figure 6. Rating assessment of the competitiveness of the potential of agroholdings of the meat-processing unit of Ukraine, 2020

Source: calculated by the authors according to data State Statistics Service of Ukraine, 2021 [32]

Thus, according to the indicators of competitiveness assessment of the potential of agroholdings of the meat-processing unit, the enterprise No. 1, has the highest rating, the second and third place belong to – No. 1 and No. 4, the agroholding No. 5 has the lowest level of rating. In order to increase the competitive potential and strengthen its position in the consumer market of agro-food enterprises in the meat-processing industry, it is necessary to develop effective management decisions in the long run.

DISCUSSION

Management of the competitive potential of agro-industrial enterprises (agroholdings) is a general economic factor of rational consumption of resources and efficient functioning of the economic system. It is known that even those agroholdings that have similar potentials often differ in the results of their activities. Under these conditions, the difference in results can be explained only by the unequal degree of accuracy of the target orientation of the system. That is, other things being

equal, the value of the result will be greater, if the system of managing the competitive potential of agroholdings of the meat-processing unit is successful.

The integration of economic processes, which ensures the rationality of the potential management system of agroholdings of meat-processing complexes, reflects the ability to streamline its components through the internal laws of economic activity, and to reproduce its functionality it is necessary to model the optimization potential of the enterprise of agro-industrial production and identify alternative ways to use it. Using a system approach to the effectiveness of potential management is appropriate for assessing its components. It covers six blocks: financial, business activity, market, labor, business process management, and innovation potential. Each block of potential is proposed to be evaluated based on selected indicators taking into account the weights set by the expert. According to the adopted method [33]

$$C_{mp} = D_{vep} \times 0.1 + D_v \times 0.3 + Dveg \times 0.25 + C_{mv} \times 0.1 + C_z \times 0.15 \quad (34)$$

where D_{vep} – the share of export revenue of the enterprise in its total revenue; D_v – the enterprise's share in the domestic market; D_{veg} – the share of export revenue of the enterprise in total export revenue by industry; C_{mv} – the coefficient of the share of material costs in the cost of production; C_z – the ratio of stocks of finished products to the average monthly volume of marketable products.

4. Labor potential (C_{pp}) [34]:

$$C_{pp} = C_{lp} \times 0.55 + C_{mms} \times 0.3 + C_{he} \times 0.15 \quad (35)$$

where C_{lp} – labor productivity ratio; C_{mms} – the coefficient of material motivation of staff; C_{he} – the ratio of industrial production personnel with higher education to the total number of industrial production personnel.

5. Business process management potential (C_{pbpm}) [34]:

$$C_{pbpm} = C_{rc} \times 0.3 + C_{suya} \times 0.7 \quad (36)$$

$$CP = C_{fp} \times 0.1 + C_{pba} \times 0.2 + C_{mp} \times 0.3 + C_{pp+0.1+} \times 0.15 + C_{pbpm} \times 0.1 + C_{pi} \times 0.15 \quad (38)$$

Thus, the efficiency of managing the potential of agroholdings in the meat-processing industry is a complex indicator that is calculated on the basis of a number of individual criteria. In this case, the assessment of the effectiveness of potential management using weights leads the individual indicators to a comparable form, which allows calculating the consolidated indicator.

The forecast indicators of the efficiency of potential management of the investigated enterprises of meat-processing unit are established Figure 7.

Thus, the highest efficiency of managing the potential of the meat-processing industry is in the agroholdings No. 7 and No. 2, but the latter has less management efficiency 9%. In the agroholding No. 6 the indicator of management efficiency is only 46.1% of the level of the reference according to the rating of

the calculation of the assessment of the effectiveness of potential management is carried out according to the algorithm:

1. Financial potential (C_{fp}) [34]:

$$C_{fp} = C_{fi} \times 0.2 + C_{cl} \times 0.3 + C_{scg} \times 0.2 + C_{wct} \times 0.3 \quad (32)$$

where C_{fi} – the coefficient of financial independence (autonomy); C_{cl} – current liquidity ratio; C_{scg} – the coefficient of sustainable economic growth; C_{wct} – turnover ratio of current assets.

2. Potential of business activity (C_{pba}) [34]:

$$C_{pba} = R_{ta} \times 0.15 + R_{ag} \times 0.25 + R_s \times 0.3 + R_c \times 0.3 \quad (33)$$

where R_{ta} – the ratio of total return on total assets; R_{ag} – return on equity ratio; R_s – the coefficient of profitability of sales; R_c – cost-effectiveness ratio.

3. Market potential (C_{mp}) [34]:

where C_{rc} – the coefficient that reflects the level of computerization of production and management processes; C_{suya} – the coefficient that reflects the presence of a quality management system (evaluated by experts on a scale from 0 to 1).

6. Innovation potential (C_{pi}) [34]:

$$C_{pi} = C_{np} \times 0.3 + C_{ia} \times 0.2 + C_{wme} \times 0.25 + C_{rfa} \times 0.25 \quad (37)$$

where C_{np} – the ratio of new products in the total volume of marketable products; C_{ia} – the ratio that reflects the share of intangible assets in the balance sheet currency; C_{wme} – the coefficient of wear of machines and equipment; C_{rfa} – the coefficient of renewal of fixed assets.

The integrated indicator of efficiency of potential management is calculated by formula (38) [34]:

the enterprise (agroholding No. 7). The practice of innovation processes in processing enterprises shows that most of the economic benefits of the new technology is brought by improvements made after this technology has found commercial application. That is, the priority is the development of innovations in the processing industry, which in turn require the introduction of new machinery and technology in agriculture. Further supporting innovations aimed at meeting the needs of the consumer market, will attract investment. Therefore, the innovative development of processing enterprises as part of agroholdings is a strategic tool to increase the efficiency of enterprise development in both domestic and foreign markets. More clearly, the general level of evaluation of the effectiveness of potential management is presented in Figure 8.

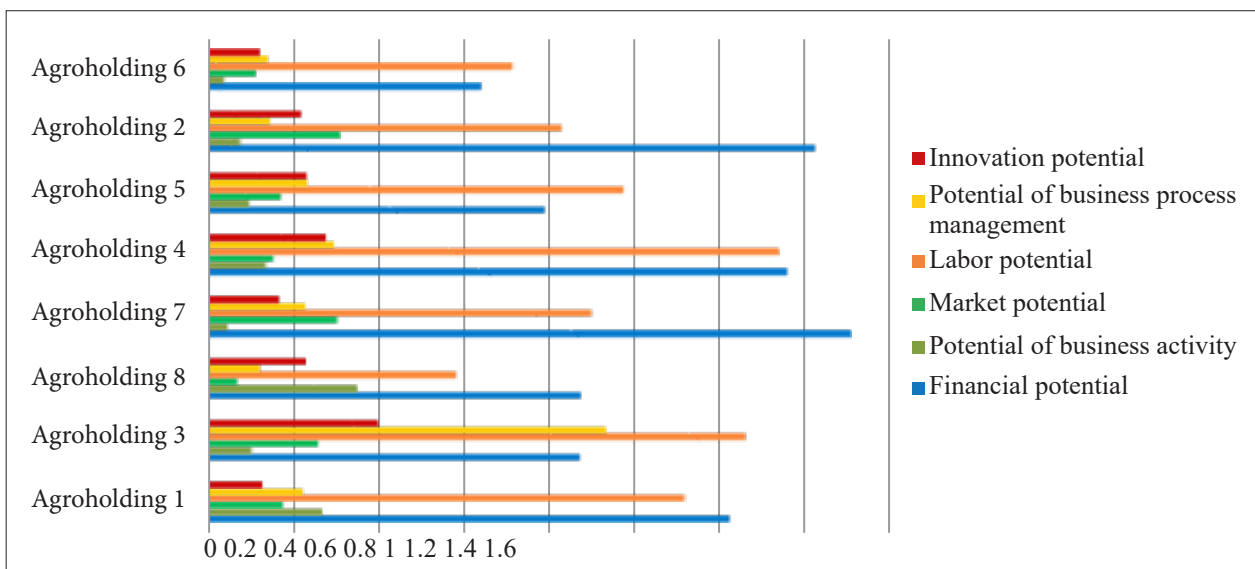


Figure 7. Forecast level of indicators of effective management of the potential of agroholdings of the meat-processing unit of Ukraine

Source: calculated by the authors

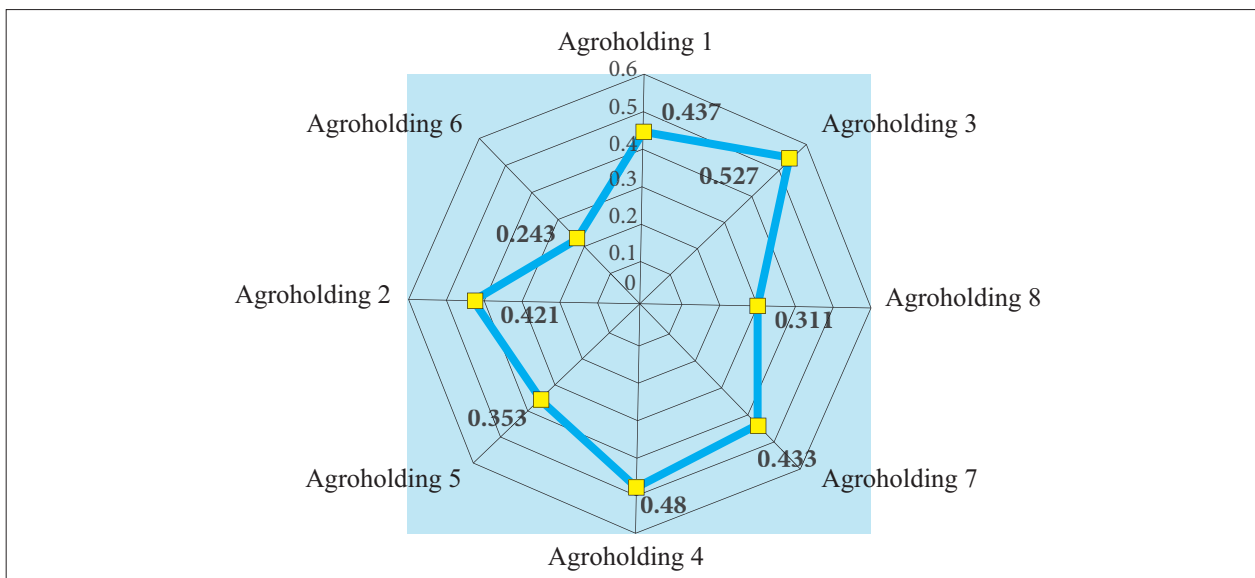


Figure 8. Forecast integrated coefficient of effective management of the potential of agroholdings of the meat-processing unit of Ukraine, 2020

Source: calculated by the authors

Calculations show that the competitiveness of the potential in most of the studied agroholdings of the meat-processing unit is average.

Thus, the constant development of competitive potential is the main condition for the effective operation of agro-industrial enterprises in a dynamic environment of the consumer market. At the same time, approaches to the development of competitive potential reflect different levels of its implementation. Most agro-industrial enterprises in Ukraine, seeking to increase competitive advantages and maintain market positions, traditionally use the strategy of two different trends: specialization and diversification. It is obvious that both of them help on the one hand to concentrate the potential of resources in the economic system, on the other – to

expand the sphere of production due to uncertainty in the prospects of the main business. It should be noted that diversification and specialization have a single nature – a form of enterprise response to changes in the environment, which aims to identify those unique properties of the potential on the basis of which through the “value chain” they can develop in the long run and ensure their own success in creating consumer value. Therefore, the value chain for a set of activities creates additional consumer value of the enterprise product. That is, as the product moves along the production line to the final consumer, each participant in the production process brings additional value to its value, which reflects a set of interrelated activities and functions in the enterprise.

CONCLUSIONS

While assessing the enterprise's position in a competitive environment we should pay attention to the problems of physical and moral wear of basic and ancillary equipment, partial or complete lack of sources of capital investment, the duration of the introduction of innovative technologies, insufficient automation of manufacturing processes, continuous growth of costs of raw materials and also efforts at the enterprise level to carry out all production processes. In addition, it is necessary to determine the effectiveness of the main functions and processes in the value chain, namely: the use of procurement of materials, settlements with suppliers, inventory management, human resources and payroll, the control of the quality of processes and products and the execution of customer orders, how quickly the company innovates, launches new products to the market. This practice allows

setting the minimum cost for the implementation of certain processes of production and sale of certain products.

Under conditions of high competition, the consumer market requires agro-food production entities, especially meat-processing units, to concentrate their efforts on the stages of reproducing the components of the potential of enterprises. Meanwhile, for the normal functioning of the market it is necessary to implement a rational distribution of time and resources between the main and non-core units, or activities. Outsourcing is a strategic alternative to deepening the specialization of enterprises. It is a special, highly efficient form of organization of business relations between enterprises, which creates a network system of production on strong long-term ties of independent market participants.

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Управління потенціалом агропромислових підприємств на споживчому ринку

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Анотація. У статті реалізовано аспекти управління потенціалом агропромислових підприємств на споживчому ринку. Запропоновано комплексний методологічний підхід до діагностики моделі оцінки управління потенціалом агропромислових підприємств, що на основі математичного апарату нечітких теорій дозволяє оптимізувати її рівень у ланцюжку сукупних компонентів, зменшити тиск чинників та обмежити конкурентні позиції бізнесу на споживчому ринку. Доведено, що економічна діагностика дозволяє виявити причинно-наслідкові зв'язки в управлінських дисфункціях та перейти до моделі сталого розвитку підприємства та ефективного використання його потенціалу. Запропоновано групову (інтегровану) систему діагностики економічних систем, яка поєднує в собі властивості традиційних «жорстких» моделей та алгоритмів, що оцінюють стан управління агропромисловими підприємствами та причини їх дисфункції у багатьох неконтрольованих потоках ресурсів, з ймовірністю збою. Обґрунтовано, що основною складовою управління потенціалом підприємства є наявність потенційних ресурсів, сукупність та взаємодія яких відкриває перспективні можливості для досягнення цілей управління. Визначено напрями оцінки вартості потенціалу агропромислового підприємства. Проведено експертну оцінку інтегрального коефіцієнта економічної стабільності потенціалу агрохолдингів м'ясопереробних підприємств України. Визначено графічно-аналітичні рівні типових проявів потенціалу та профілю його складових на підприємствах агропромислового виробництва м'ясопереробної галузі. Розраховано стандартизовані коефіцієнти рейтингування сільськогосподарських господарств м'ясопереробних підприємств України за їх потенціалом. Встановлено прогностичний рівень показників та інтегральний коефіцієнт ефективного управління потенціалом підприємств агропромислового комплексу

Ключові слова: земельний та ресурсний потенціал, земельні відносини, рента, врожайність, собівартість, дохід, рентабельність аграрія



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Consolidation of Public Finances as a Tool for Minimising Disparities in the Sectoral Structure of the National Economy

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Abstract. The present paper sets the task to consider the issues of public financial resources consolidation in the context of disclosing tax and budgetary policy tools to minimise disparities in the sectoral structure of the Ukrainian economy. The relevance of the study is determined by the topicality of the issues of consolidation and subsequent synchronisation of the finances of public structures in order to create the necessary conditions to minimise the differences between sectors of the Ukrainian economy. In this context, it is extremely important to consider the issues of public finance consolidation through the prism of disclosing the fiscal policy tools as a means of minimising the disparities in the sectoral structure of the Ukrainian economy. The issues of budgetary policy and the economy of Ukraine are extremely important from the standpoint of assessing the correctness of the chosen course of development of Ukrainian society in general and individual sectors of the national economy in particular. The purpose of this study is to assess the real state of the country's budgetary policy in general and in the context of the consolidation of public finances as a tool to minimise these disparities in particular, as well as to consider some aspects of the current status of the Ukrainian economy. The leading approach of the study is a combination of quantitative and qualitative analysis of the matter at hand. The main results of the study were: an assessment of the level of disparities in the distribution of funds from the state budget of Ukraine for 2020; determination of the main directions for the consolidation of public finances when planning the state budget for the current financial year. Prospects for further research in this direction are determined by the importance of various aspects of the distribution of public finances in various spheres of the national economy and the need to create optimal conditions for their proper distribution. The applied value of this study lies in the assessment of the prospects for consolidating public finance as a tool to minimise the disproportions in the sectoral structure of the Ukrainian economy and the possibility of searching for and then introducing optimal ways for a qualitative resolution of this issue

Keywords: consolidation of public finance, national economy, economic sector, sectoral structure of the economy, public finance, funding recipient



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INTRODUCTION

Today, the dynamics of the structural development of the Ukrainian economy do not correspond to the general patterns of structural changes occurring in the economies of the leading world powers. It consists of an increase in the share of high-tech manufacturing industries, telecommunications, financial and business services, as well as socially oriented types of economic activity, ahead of the development of science-oriented, high-tech industries [1].

The modern sectoral structure of the national economy of Ukraine contains a division into primary, secondary, and tertiary (transactional) sectors. Gross Domestic Product has a similar sectoral structure. The establishment of a sectoral economy is functionally linked to the development of a new type of economy – post-industrial [2; 3]. Each sector of the economy is characterised by certain structure, hierarchy, proportions, subsystems, as well as economic objects. The structure of the national economy includes a set of interchangeable sectors that create meso-levels, meso-chains and form the macroeconomics of Ukraine [4]. The primary sector of the Ukrainian economy covers the agricultural sector, as well as adjacent spheres. The secondary sector includes industrial sectors: food and pharmaceutical industries, supply of electricity, gas, water, and construction operations. The tertiary sector of the economy includes service industries: wholesale and retail trade, insurance and financial activities, transport, education, public administration, social assistance, health care [4].

The qualitative characteristics of the sectoral structure of the Ukrainian economy are significantly inferior to those of the leading European countries. Today, the quality of the structure of the Ukrainian economy is at the level of the 1970s in countries such as the UK, Germany, Italy, and Spain [4]. At the same time, in the conditions of a constant rise in the cost of raw materials and energy resources, the deterioration of the Ukrainian technological base, and at the same time, in the presence of significant industrial, scientific, technical, human potential, and significant competitive advantages over other countries (fertile land, favourable geographical location), minimising the disproportions in the sectoral structure of the national economy of Ukraine should become a combined model for the implementation of structural adjustment. The unification of several interconnected structural flows should become the mainstream of this process. The accelerated rates of industrial development in combination with the stimulation of innovations by the state in areas “critically lagging” behind post-industrial economies, contribute to the achievement of high rates of economic growth and competent state budget planning [5].

In the context of the aforementioned, the issues of public finance consolidation as an effective tool for minimising disproportions in the sectoral structure of the national economy are of paramount importance in planning the state budget, which is the basis of the national economy. Consolidation of public finances involves the

combination and subsequent synchronisation of data from reports of a group of financial structures in order to form an accurate understanding of the financial situation of public consolidated financial structures of various sectors of the national economy. Consolidated financial statements represent the most objective information regarding investment in the activities of enterprises, as well as their assets and the procedure for control over them. Thus, the quality control of public finances and the ability to influence financial policy through them is carried out.

The national economy of any country is a complex, consolidated system that includes social, organisational, economic, socio-political, and other components. It is characterised by the aggregate potential of natural resources, production, labour, scientific and technical components. In the process of development of the country's economic system, the establishment and improvement of its national market take place. It includes the organised functioning of its segments: capital markets and goods, various services, immovable property, labour resources, the stock market, intellectual property markets, and production assets. The national economy is undergoing constant structural and organisational changes characteristic of the specific features of the country's economic system, as well as certain trends and features and patterns of its development. Today, the sectoral structure of the Ukrainian economy in terms of its qualitative characteristics is significantly inferior to the indicators of the economically leading countries. This is a confirmation of the need for deep structural changes in the economy of Ukraine. The issues of consolidation of public finance as a tool for minimising the disproportions in the sectoral structure of the national economy play a crucial role in this context.

LITERATURE REVIEW

An analysis of the literature on the subject of public finance consolidation as a tool for minimising the disparities in the sectoral structure of the national economy demonstrates a wide range of researchers' assessments. Assessment of various aspects of this complex issue contributes to its comprehensive coverage and identification of the main factors that influence the budgetary policy of Ukraine and its economic potential.

So, [4] conducting a study of the sectoral structure of the Ukrainian economy, note the need for structural reform. According to the researchers, “the search for an optimal model of sectoral structuring for national economies turns out to be impossible since scientific and technological progress contributes to the constant improvement of the economic structure, the emergence of fundamentally new types of economic activity, which are extremely difficult to group with traditional economic sectors” [4]. For his part, [6] analysing the current state of the economy of modern Ukraine, notes “The national

economy existing in Ukraine today is based on the residual phenomena of a planned economy in conjunction with wild elements of a market economy, mostly of a criminal nature. The sharp decline in the standard of living of the population led to several social upheavals. The domestic economy faces a solution to the problems of the shadow economy and the implementation of technologies for general sustainable development” [6].

M.V. Abazova and F.B. Tatueva [7] while researching on the advantages and disadvantages of the market economy system as a whole, noted the existence of two main models of transformation of the planned economy into a market economy: the model of “shock therapy” and the model of gradual economic reform. In the first case, there is a large-scale destruction of the state economic sector in a short time. In the second – “the preservation of a strong public sector for a rather long period, gradually transferring part of its functions to the hands of private business” [7]. At the same time, researchers note that “In the economic literature, the market economy is defined as “a system of organisation of the national economy based on goods-money relationships, a plurality of forms of ownership, free competition between producers and citizens who own their labour force”. Or as an economy, based on “the principles of free enterprise, a variety of forms of ownership of the means of production, market pricing, competition, contractual relations between business entities, limited government interference in economic activity” [7]. Similar positions are upheld by O.V. Savosina when she analysed the processes of countries’ transition to a market economy [8]. According to the researcher: “The establishment of a modern market economy is a rather complicated matter since the command-administrative system that has developed over decades has to be radically transformed. The market system operates on fundamentally different mechanisms of economic development than the command-administrative system, therefore it is impossible to form it in a short time. It is impossible to quickly change the existing socio-economic structure of society and transform property relations, create a market structure and an appropriate regulatory framework, and finally form a new worldview among business entities” [8-10]. Thus, modern studies state the complexity of creating a high-quality structure of a modern market economy and the need for its formation under the principles of reaching agreements between business entities and preserving its sectoral structure.

At the same time, D.S. Lvov, P.G. Porshenevsky, and Yu.A. Chernov assessing the pace and quality of economic transformations in Ukraine, note “... today it is generally accepted that in terms of the efficiency of the country’s economic development, increasing the productivity of national capital is the main task [11]. But this task should be clarified: an increase in investment in human resources is required, the productivity of which is the most important factor for solving the full range of social problems” [11]. In addition, the authors

point to the urgent need to determine the key characteristics of the formation of the country’s economic strategy in modern conditions. In their opinion, “the formation of a true economic strategy should be determined by the existing structure of society, as well as its prospective economic development. From this perspective, any formulation of economic and financial tasks, such as the fight against inflation, poverty, must correspond to the complexity of the social issues facing the country” [11; 12].

Thus, a review of the available literary sources clearly demonstrates the diversity of opinions and assessments of researchers on the issues of consolidating public finances as an effective tool for minimising the disparities in the national economy of Ukraine. This fact determines the breadth of the spectrum of research and the possibilities of forming versatile conclusions based on their results.

MATERIALS AND METHODS

This study sets the task of investigating the issues of public finance consolidation as a tool for minimising the disproportions in the sectoral structure of the national economy of Ukraine. The analysis of methods of public finances consolidation and the possibilities of resolving this issue within the framework of the existing sectoral structure of the Ukrainian economy is carried out.

The methodology of research combines quantitative and qualitative analysis of the matter at hand. A deep quantitative analysis of the materials available in the study is performed, a comparison of the budgetary policy of Ukraine and its economy with leading European countries is carried out. For this purpose, a significant number of papers on the issues of consolidating public finances as a tool for minimising the disproportions of the national economy were thoroughly examined. The main factors influencing the observance of the proper sequence of public finance consolidation and determining the state of the sectoral structure of the economy are identified. A system of correspondences between the questions stated for research and the results obtained is being built, which contributes to a more thorough study of the topic and obtaining final, comprehensive results. In the course of preparing the conclusions for the present study, a significant amount of information was taken from foreign publications on the subject.

Moreover, a comparison of data obtained from foreign publications with findings of Ukrainian researchers makes it possible to obtain a qualitative picture of the budgetary policy of Ukraine, and compare the economic situation in Ukraine with that of developed European countries. This aspect seems to be extremely important from the standpoint of forming conclusions, which objectively reflect the real situation in the field of disproportions in the sectoral structure of the Ukrainian economy. In the context of the matter in hand, the studies by different authors are compared and the general trends and patterns in their views are identified regarding various

aspects of the consolidation of public finances. Based on the performed quantitative analysis, a qualitative analysis of its findings is carried out, which is necessary for the formation of final conclusions based on the results. Modern methods of public finance consolidation are designed to provide an opportunity to reduce the operating costs of enterprises that form the basis of the functioning sectors of the Ukrainian national economy. Moreover, the disproportions in the sectoral structure of the national economy cause a significant disparity in the functioning of its individual industries, which has a negative impact on the level of economic development of the country. Consolidation of public finances requires a thorough study, given the variety of aspects that it includes, and the need for their consideration in order to fully understand the essence of the issue. In this context, the methodology chosen for the study seems to be optimal for the qualitative resolution of issues at hand, which creates the preconditions for its subsequent use in further scientific research in this direction.

RESULTS

The study of the issues of public finance consolidation as a tool for minimising disparities in the sectoral structure of the national economy led to the following results.

For a high-quality display of the current level of the economic system of the state as a whole, it is necessary to highlight the sectoral structure of the national economy by type of activity. This, in turn, helps to identify opportunities for the consolidation of public finances in order to minimise the disparities in the sectoral structure of the national economy. To correctly assess the level of structural disparities in the Ukrainian economy today, it should be analysed at the macro level. The growth rates

of individual industries and components of the national economy are different, just as the growth rates of prices for various resources are different. This leads to significant dynamics of economic disparities and economic ties between individual industries.

The diagram below shows the structure of the Ukrainian economy, taking into account the division into primary, secondary, and tertiary economic sectors. Data are presented as of 2018 and 2019 (Fig. 1).

As can be seen from the diagram above, at the end of 2019, the share of the gross product in the tertiary sector amounted to 33%, which is 5% more compared to the year 2018. When compared with economically developed countries, this figure is significantly less than the same indicator of their economy, which is about 70%. The share of the secondary sector in the economy of Ukraine at the end of 2019, amounted to 46%, which is considered a low indicator for countries with an economy in transition, to which Ukraine can be attributed. For comparison, the same indicator for Poland for the same period was 52%. In general, the data presented in the diagram indicate the unevenness of the economic structure of Ukraine and the comparative lag of the Ukrainian economy behind the economies of more developed European countries. Competent implementation of public finances consolidation at various stages of operation of sectors of the Ukrainian economy contributes to a decrease in the existing proportions between the sectors of the economy and an overall increase in GDP in specific economic sectors.

The diagram below shows the structure of Ukraine's GDP by end-use category. The period from 2015 to 2019 was taken for the assessment (Fig. 2).

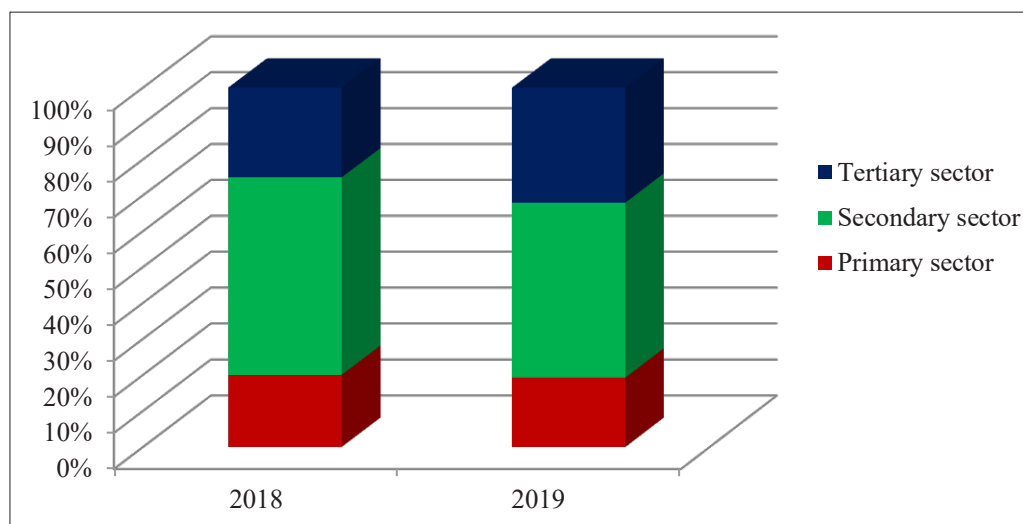


Figure 1. The structure of the Ukrainian economy as of 2018 and 2019 taking into account the division into primary, secondary, and tertiary sectors

Source: [13]

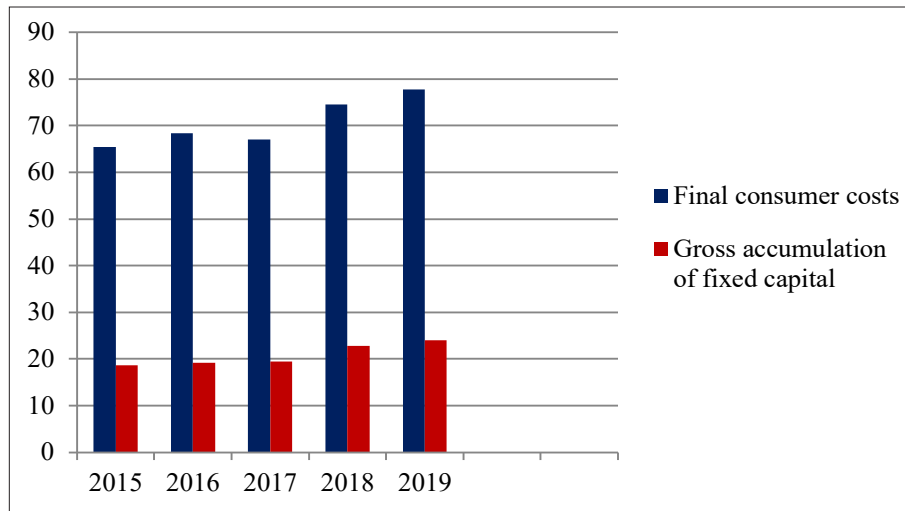


Figure 2. Structure of Ukraine's GDP by categories of its end use for the period from 2015 to 2019

Source: [13]

The most important feature of the country's economic development in the post-crisis period is a sharp decrease in the level of gross accumulation of fixed capital, which is much less than in the pre-crisis period. So, at the beginning of 2008, this indicator was 26.8%, as at the end of 2019 it has not been achieved. This situation is not conducive to meeting the needs of economic recovery. To further minimise such disparities, a set of measures is required:

1. Reducing the tax burden for enterprises belonging to the specified economic sectors.
2. Reducing the expenses of these enterprises for secondary economic needs.
3. Balancing the state policy in the budgetary sphere at the expense of internal and external credit funds.
4. Carrying out measures to consolidate public finances in various spheres of economic activity of the state in order to minimise disparities in economic sectors.

Consolidation of public finances involves tracking the flows of budget funds allocated for the practical solution of tasks related to the activities of specific sectors of the economy. A well-built ratio of export and import volumes in this context is of great importance for the country's economy and its budgetary policy. The ratio of these indicators correlates with the division of countries into those that import capital (export) and those that export capital (import). It is generally accepted that the surplus of free capital should be combined with the surplus of goods and services, which contributes to the excess of exports over imports. At the same time, the lack of capital, combined with a weak level of protection of the national economy of Ukraine from external influences, necessitates an excess of the volumes of imported goods and services over the volume of exported goods.

In addition, the planning of the state budget of the country involves the consolidation of funds allocated for solving the problems of budget planning in the framework of the implementation of specific programs of an economic nature. In this context, the issues of budgetary policy should be considered through the prism of organising relations in the financial sphere at the stages of forming the budget revenue and spending, as well as the regulation of various spheres of interbudgetary relations. The consolidation of public finances in matters of budgetary policy has a significant impact on the size of financial resources and their proportions. Its centralisation is carried out by state authorities while determining the structure of expenditures and prospects for the targeted use of state budget funds allocated for the development of the state economy.

The budgetary policy of Ukraine regulates all relations in the financial sphere while accounting for finances passing between enterprises, organisations, and the state, which is facilitated by accounting for tax revenues, conducting investment activities, as well as planning budget allocations in priority areas of sectoral economic activity. In modern Ukraine, there is a purposeful influence of the state on specific economic sectors, which contributes to a change in the structure of government spending, state property, and taxation, which act as instruments for conducting state policy. Its main parameters are reflected in the state budget and are an effective tool for the distribution of public finances and their consolidation.

Table 1 provides information on the trends in the compliance of the state budget of Ukraine for 2020. Shown are the planned indicators of distribution of funds, items of income and expenses, as well as indicators of lending and budget deficit on a monthly basis.

Table 1. Compliance of the state budget of Ukraine for 2020 (mln. UAH)

2020	Income	Expenses	Crediting	Balance (budget deficit)
Planned indicators	1095580.4	1182010.4	7845.8	-94275.7
January	50968.5	66282.0	-99.6	-15213.9
February	122773.4	144739.6	-395.4	-21570.4
March	211033.9	244497.4	-730.8	-32732.7
April	314847.3	340116.7	-961.8	-24307.5
May	388260.1	438375.7	-1334.4	-48781.4
June	519390.5	536913.5	1315.6	-18839.1
July	588456.0	636467.4	3184.3	-51195.4
August	688695.0	727004.6	2877.0	-41186.6
September	765108.6	843253.2	3580.8	-81725.3
October	84437.8	950842.3	3757.6	-112162.1
November	-----	-----	-----	-----
December	-----	-----	-----	-----

Source: [14]

The excess of the income over the expenses is called the budget surplus, while the excess of the expenses over the income side is called the budget deficit.

Table 2 presents the data on government revenues for the beginning of December 2020. The same data can be presented in the form of a diagram (Fig. 3).

Table 2. Revenues to the state budget of Ukraine for 2020 financial year

Date	Receipt (mln. UAH)
As of 01.02.2020	50725.4
As of 02.03.2020	112632.7
As of 01.04.2020	210685.8
As of 04.05.2020	314536.0
As of 01.06.2020	388765.6
As of 01.07.2020	519451.5
As of 03.08.2020	589645.3
As of 01.09.2020	688947.3
As of 01.10.2020	764778.5
As of 02.11.2020	842564.7
As of 01.12.2020	944726.5
As of 02.12.2020	946468.4

Source: [14]

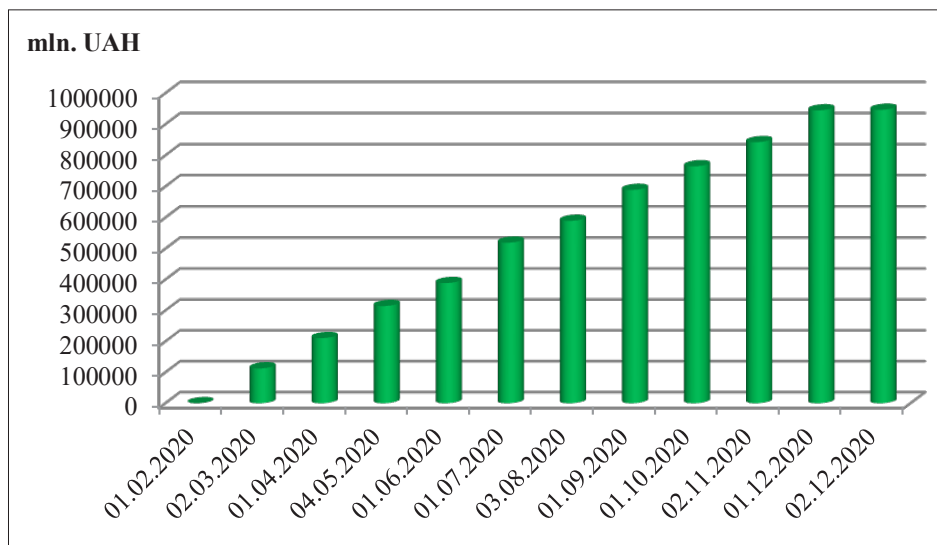


Figure 3. Revenues to the state budget of Ukraine for 2020 financial year, mln. UAH

Source: [14]

Thus, throughout the entire 2020 financial year, there is a progressive increase in the volume of revenues to the state budget of Ukraine, which has a positive effect on the dynamics of the development of the economic situation in the country.

The diagram below clearly demonstrates the structure of the consolidation of public finances in Ukraine by the most significant budget sectors as of 12.01.2020. As can be seen from the data presented, the budgeting and social protection spheres constitute the most

significant part of the state budget (27% of the total). Almost 15% of the total volume of budgetary appropriations is allocated for national functions, 13.8% of the total volume of the state budget is spent on inter-budgetary transfers, 12.5% is spent on public safety and order, 9.6% of costs are the needs of the state economy, 9.2% is allocated for the needs of the defence industry, 7.8% of the state budget is allocated for the needs of the health care system, 4.3% for the needs of the education system (Fig. 4).

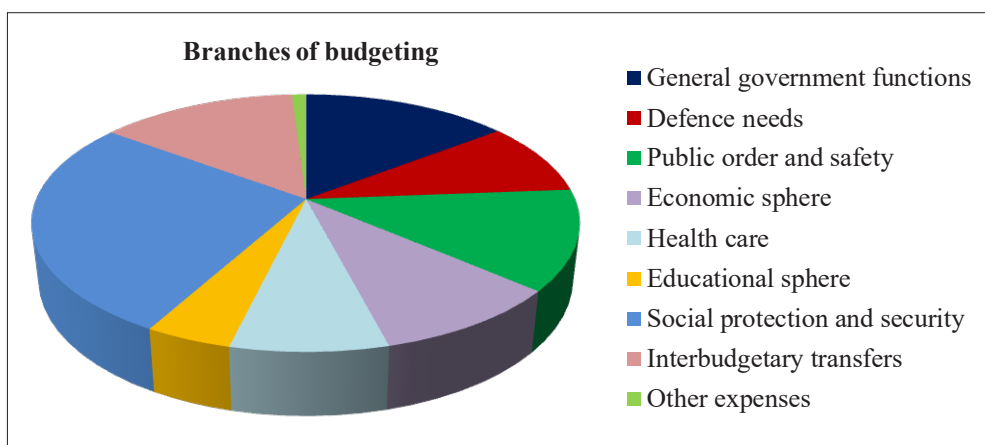


Figure 4. Consolidation of public finances in Ukraine by the most significant budget sectors as of 01.12.2020

Source: [14]

Thus, the issues of the consolidation of public finances in Ukraine as a tool for minimising the disparities in the sectoral structure of the country's economy as of 2020 represent a complex set of issues of an economic, socio-political, and social nature. The full functioning of the country's economy and the standard of living of modern Ukrainian society depend on their timely and competent resolution.

DISCUSSION

The complexity and volume of the set of issues related to the consolidation of public finances as a tool to minimise the disparities in the sectoral structure of the national economy determines the diversity of opinions expressed by modern researchers.

Thus, a group of authors, represented by [11] in their studies of economic transformations in modern Ukraine,

note the cyclical formation of successive economic systems. According to the authors, "... the process of renovation of old and establishment of new economic systems occurs at a lower cost, while "transition periods" completely exclude the "interruptions of continuity" caused by current economic transformations" [11]. Thus, the fact of cyclical changes in the economy of the state and the inconstancy of the sectors of the economy are emphasised. In turn, [15], examining the characteristic features of the structural imbalances in the development of Ukraine, indicates a low level of development of the national economy. According to the researcher, "the imbalance in trade in goods on foreign markets in recent years has caused an overall negative foreign trade balance of Ukraine and indicates a low level of development of the national economy" [15]. The author also notes that "the state of the sectoral structure and qualitative parameters of the structure indicates a low level of development of competitive opportunities in Ukraine. "Structural imperfection of the economy will lead to a significant decrease in its competitiveness and an increase in threats to the country's economic security in the medium term. At the same time, the approach of the structure of the Ukrainian economy to the structure of Poland is being monitored, where the stage of transition to highly developed European countries has already been partially passed" [15].

The issues of consolidation of public finances in general and in relation to various aspects of minimising the disparities in the sectoral structure of the state economy, in particular, are considered in the works of foreign authors researching this issue. Thus [16], examining various aspects of changes in the Indian economy note "... the deterioration of the base GDP growth in India by 7.8% in 2016 is caused by the insufficient openness of the country's economy to the processes of consolidating public finances in certain industries and unpreparedness to make changes in the activities of several enterprises" [16; 18]. In turn, [18], in his study of public finance issues and the specifics of their management, notes "A thorough analysis of various aspects of the welfare of the state economy clearly demonstrates the dependence of the features of the course of economic processes on maintaining the sequence of financial consolidation in the context of reducing the disproportions in the functioning of individual economic sectors" [18-20]. Thus, foreign authors emphasise the importance of the consolidation of public finances to reduce to the minimum indicators of disparities in the economic development of the state.

A group of authors, represented by [4] who researched in the field of the sectoral structure of the Ukrainian economy, note the importance of competent coverage of the issues of the sectoral structure of the economy of any country. According to scientists and researchers, "The reflection of the qualitative level of development of the economic system as a whole is carried

out by illuminating the sectoral structure of the national economy by type of economic activity. An effective sectoral structure of the economy, which corresponds to a socially-oriented model of a market-type economy and is based on the use of both competitive advantages in the world division of labour and the economic advantages of international integration, is the guarantor of the independence of any country and the guarantee of its dynamic development" [4]. L.V. Tranchenko adheres to a similar point of view, conducting independent studies of structural changes in the Ukrainian economy [6]. According to the scientist, "... the method of cardinal reform, chosen to bring the economy out of the crisis, presupposes the complete abolition of the planned economy and the establishment of an opposite policy of economic liberalism. The previously widely used methodology of monetarist economic policy was poorly adapted to the conditions of the national economy. Therefore, numerous technologies that previously gave positive results in the conditions of the economies of Western countries, in the conditions of the Ukrainian economy came to nothing" [6; 21].

Thus, the opinions of researchers emphasise the ambiguity of the matter at hand and the need for further study. This will help to identify additional aspects that may have an impact on the economic structure of countries, after the preliminary planned consolidation of public finances in them.

In this regard, the consolidation of public finances in specific areas ensures control over their intended use and contributes to the establishment of the necessary conditions for minimising disparities between individual economic sectors. In general, the imbalance in the sectoral structure of the economy is caused by a wide range of factors. Among such factors, the uneven distribution of funds from the state budget in the conditions of uneven situations in world markets and the cyclical nature of economic crises throughout the world in general and individual states, in particular, are of paramount importance. Purposeful government subsidies to specific sectors of budget financing ensure the maintenance of a certain level of functioning of economic structures. The amount of allocated funds determines the nature of their functioning and the direction of activity. In general, the budgetary policy of Ukraine today includes a set of measures for the targeted distribution of revenues to the state budget and competent control of their subsequent targeted use. Consolidation of public finances plays a primary role in this aspect. It is due to the accumulation of the volume of money supply for targeted distribution to specific areas of activity in the given economic sectors that the minimisation of discrepancies between the individual sectors of the state economy is achieved. In this context, a great responsibility is assigned to the bodies controlling the receipt of funds to the state budget (tax authorities), since the quality of accounting for state

budget funds and their subsequent competent targeted use depends on the results of their activities. In addition, the consolidation of public finances in relation to the activities of specific enterprises in various sectors of the economy in crisis and post-crisis periods ensures the safety of enterprises' funds during periods of economic instability for their subsequent competent target use.

CONCLUSIONS

The study of the issues of public finance consolidation as a tool for minimising disparities in the sectoral structure of the national economy led to the following conclusions. The state of the economic structure of the state is determined by a wide range of factors. The most important of such factors are: planning the state budget, clearly defining the current budget, as well as identifying priorities in matters of optimising finance in order to reduce disparities in the sectoral structure of the state's economy. The issues of consolidation of public finance, in relation to the sectoral structure of the economy of Ukraine, are extremely complex and involve many options for approaches to their resolution. In particular, representation

of the current level of development of the state economy requires coverage of its sectoral structure in specific areas of economic activity. The independence of the state and the dynamic development of its economy are achieved through the consistent establishment of a market-type economy and its base involves the use of competitive advantages in world markets, as well as the economic advantages created by international integration activities.

In general, taking into account the factors listed above and the existing trends, it can be concluded that the model of the Ukrainian market economy, which has formed today, is a synthesis of the characteristic features of the market economy of developing countries, on the one hand, and the preserved features of "oligarchic capitalism" on the other. The relative economic growth in the last post-crisis years gives grounds to conclude that the crisis of transformation of the Ukrainian economy is over. The subsequent consolidation of public finance as a tool for minimising the disproportions in the sectoral structure of the country's economy should become decisive in ensuring economic growth and achieving stability in the development of Ukrainian society.

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Консолідація державних фінансів як інструмент мінімізації диспропорцій у галузевій структурі національної економіки

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Анотація. У цій роботі поставлено завдання розглянути питання консолідації державних фінансових ресурсів у контексті розкриття інструментів податкової та бюджетної політики для мінімізації диспропорцій у галузевій структурі української економіки. Актуальність дослідження визначається актуальністю питань консолідації та подальшої синхронізації фінансів державних структур з метою створення необхідних умов для мінімізації відмінностей між галузями української економіки. У цьому контексті надзвичайно важливим є розгляд питань консолідації державних фінансів через призму розкриття інструментів фіскальної політики як засобу мінімізації диспропорцій у галузевій структурі української економіки. Питання бюджетної політики та економіки України є надзвичайно важливими з позицій оцінки правильності обраного курсу розвитку українського суспільства загалом та окремих галузей національної економіки зокрема. Метою даного дослідження є оцінка реального стану бюджетної політики країни в цілому та в контексті консолідації державних фінансів як інструменту мінімізації цих диспропорцій зокрема, а також розгляд деяких аспектів сучасного стану державних фінансів української економіки. Провідним підходом дослідження є поєднання кількісного та якісного аналізу досліджуваної матерії. Основними результатами дослідження стали: оцінка рівня диспропорцій у розподілі коштів державного бюджету України на 2020 рік; визначення основних напрямів консолідації державних фінансів при плануванні державного бюджету на поточний фінансовий рік. Перспективи подальших досліджень у цьому напрямку визначаються важливістю різноманітних аспектів розподілу державних фінансів у різних сферах національної економіки та необхідністю створення оптимальних умов для їх правильного розподілу. Прикладна цінність даного дослідження полягає в оцінці перспектив консолідації державних фінансів як інструменту мінімізації диспропорцій у галузевій структурі української економіки та можливості пошуку та подальшого впровадження оптимальних шляхів якісного вирішення цього питання

Ключові слова: консолідація державних фінансів, національне господарство, сектор економіки, галузева структура економіки, державні фінанси, одержувач фінансування

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