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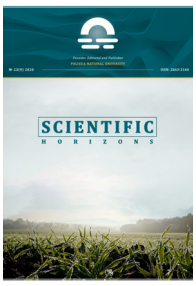

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Experimental Studies of Structural and Technological Parameters of a Downdraft Gasifier Based on Plant Biomass

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Abstract. The relevance of the study is conditioned upon the need to develop and implement structural and technological solutions to improve the efficiency of the chemical and thermal conversion of biomass into combustible gas. Within the framework of the above, the authors of this paper have designed a downdraft gasifier running on plant biomass. The presented research links the heat quantity received from the utilisation of syngas produced during the gasifier operation cycle with the parameters of the gas blow regime and the physico-chemical properties of biomass. For an in-depth study of the influence of the gas blow regime on the yield and calorific value of syngas produced from biomass, the authors introduce the concept of the blow coverage quality coefficient. This coefficient describes the quality of the cross-section coverage of the gasification chamber neck with gas currents of the tuyere zone. The purpose of this study is to establish the influence of the blow coverage quality coefficient, the volume of blow gases and the void ratio of the bulk biomass layer on the heat quantity received from syngas produced during the gasifier operation cycle. A multi-factor experiment was planned and performed, which relates the dependent factor to variables, and the corresponding response surfaces were constructed. The research findings are that the maximum value of the heat quantity received from the utilisation of syngas produced during the one-hour gasifier operation cycle was 519 MJ. This value is achieved with 0.8 blow coverage quality coefficient and a blow gas volume of 47.4 m^3/h and 46.75% void ratio of the bulk biomass layer. The measurement results are highly consistent with the calculated data. The coefficient of determination was R^2=0.983. The practical value of this study is to substantiate the rational design and technological parameters of the downdraft biomass gasifier operation, which will increase the efficiency of biomass energy production. The findings presented in this study can be used both to design new gasifiers and to improve the efficiency of the available ones

Keywords: downdraft gasifier, gasification chamber, syngas, tuyere belt, void ratio, blow coverage quality coefficient

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INTRODUCTION

Successful technical solutions in the context of creating new samples of gasifier equipment and a thorough analytical study of the production processes of combustible syngas from carbon-containing raw materials indicate the modernity and relevance of the subject under study. Studies [1; 2] analyse global trends in the successful introduction of technologies and present means of producing combustible syngas from biomass, both for scientific and commercial purposes. Depending on the energy needs and availability of raw materials, gasifier designs with fixed bed, fluidised bed and entrained flow layers of different capacities are intensively developing. For example, in the USA, Austria, Germany, and Denmark, fluidised bed and entrained flow gasifiers are commonplace, producing over 80% of syngas, the calorific value of which reaches 18...20 MJ/nm^3 [3]. In the Philippines, Latvia, Lithuania, Estonia and Ukraine, fixed bed gasifiers are most commonly operated [4]. Such types of gasifiers have a capacity of 10 kW–1 MW and are more suitable for small-scale applications [4; 5]. The calorific value of syngas produced in fixed bed gasifier is low and amounts to only 5...7.5 MJ/nm^3. However, the substantial advantages of gasifiers of this type are the simplicity of design and operation, the possibility of efficient operation on plant biomass, and the low content of resins in the produced gas (20-30 mg/m^3) [5]. Therefore, for countries where agriculture develops at the level of farming, it is more typical to develop fixed bed gasifiers, namely downdraft gasifiers.

However, despite the advantages, the use of fixed bed gasifiers does not always allow getting the expected results. The reason is a number of technical difficulties relating to the lack of practical data [3-5]. Such issues are methods for improving the efficiency of production of combustible gases from non-condensing raw materials (grain straw, sunflower husk, corn stalks) and methods for ensuring the quality of the gas produced (chemical composition, calorific value, absence of particulate matter and resins) [6]. There are technological and constructive ways to solve these difficulties. In particular, structural ways include modernisation of the gasifier design (hopper, gasification chamber, grate, ash pan, etc.) [5; 7]. Technological ways provide for the development of a gas blow regime [8]; maintenance of high temperatures in the gasification zone [9]; ensuring stable pressure [10]; increasing the reactive surface of fuel [11].

However, despite a considerable number of published scientific papers, the issue of improving the efficiency of fixed bed gasifiers was considered mainly in terms of increasing the calorific value of the generated syngas by increasing the content of the main combustible components in the gas composition (CO and H_2). The amount of gas produced per cycle (or unit of time) is almost not covered. The total heat quantity received from the utilisation of syngas produced during the gasifier operation cycle depends not only on its qualitative chemical composition, but also on the quantity. An increase in both each component separately and two simultaneously will lead to an increase in the total heat quantity received from the utilisation of syngas produced during the gasifier operation cycle in the corresponding heat engineering equipment. Therefore, a slight deterioration in the quality of syngas is acceptable if this is compensated by an increase in its volume produced per unit time. Since the quality and quantity of syngas produced are largely related to the gas blow regime of gasifier operation, this allows adjusting the supply of blow gases necessary for the gasification within a wider range.

Therefore, the issue of improving the efficiency of a gasifier, which is determined by a complex indicator of the heat quantity received from the utilisation of syngas produced during the one-hour gasifier operation cycle, is relevant and needs to be studied.

Given the above, the purpose of this study is to establish the influence of the blow coverage quality coefficient, the volume of blow gases and the void ratio of the bulk layer of biomass on the heat quantity received from the utilisation of syngas produced during the gasifier operation cycle.

The concept of the blow coverage quality coefficient k is introduced, which describes the degree of coverage of the chamber neck by tuyere zones created by air currents.

To achieve *this purpose*, the following tasks required solving:

– to design a downdraft gasifier running on plant biomass and a blow gas preparation and supply unit;

– to determine the dependence of heat quantity received from syngas, that was produced during one-hour cycle of gasifier operation, from the blow coverage quality coefficient, blow gases volume and the void ratio of bulk biomass layer.

LITERATURE REVIEW

In the process of chemical and thermal conversion of solid fuel to gaseous fuel, numerous intermediates are formed in fixed bed gasifiers, which have a substantial impact on the quality and quantity of the final gasification product – syngas [12]. These intermediates are water vapor of chemical and hygroscopic moisture of the fuel and gases, various distillates developed during the dry distillation of fuel [13].

The chemical composition and caloric content of syngas, which describe the degree of perfection of the gasification process in general, depend on the conditions that are maintained in the gasification chamber, namely: the temperature of the reaction layer of fuel, i.e., the zone of the chamber where the reactions of the formation of water and air gases occur and where distillates coming from the hopper burn and are subject to cracking; the physical and chemical properties of fuel (density, grain, void ratio, reactivity); the uniformity of fuel

intake into the chamber; the load mode of the gasifier, which determines for a certain geometric shape of the gasification chamber the speed of movement of gas masses in the and the time of their contact with the fuel surface [14].

Changes in the above-mentioned intermediates and physico-chemical conditions of the operation depend on the gasifier design features: the geometric shape of the chamber; the profile, dimensions, quantity and method of installing tuyeres that supply blow gases to the gasification zone; the angle of inclination of the hopper cone and the degree of its heating; as well as on external influences (movement of the grate, fuel stoking, gasifier vibrations) [7; 15]. The above list of factors that affect the gasification flow indicates the difficulty of considering the impact of each of them separately. In addition, numerous studies [1; 3-5; 14; 15] have proved that most of these factors are variables, which determines the variability of the gasification and, consequently, the low quality of gas.

According to [15; 16], one of the main factors that controls the thermodynamics of the gasification is the temperature in the gasification chamber, the value of which also determines the cracking of resins and other dry distillation products. The numerical value of the temperature depends on many factors, the main of which are as follows: the speed of blow gases coming out of the tuyeres and their temperature; the number and location of tuyeres; the configuration of the chamber; combustion intensity; humidity and void ratio of the fuel; thermal insulation quality of the hopper. The study [17] notes that the main reason for fluctuations in the temperature of the reaction layer during gasification is the uneven deposition of fuel near tuyeres. The reason for this phenomenon is the ability of fuel to hang and form arches. As a result, the combustion intensity decreases, which is expressed by the value of the hourly consumption of conditionally burned fuel per 1 m^2 cross-sectional areas along the tuyere belt. This worsens the flexibility of the gasification and the quality of syngas.

The influence of combustion intensity on the flexibility of the gasification is also noted in the study [18]. The authors note that as the diameter of the tuyere belt increases, the area of the combustion mirror and the mass of fuel that creates the reaction layer increase. A sharp increase in gas consumption by consumer equipment leads to the fact that the increase in the temperature of the reaction layer lags behind the growth of gas masses. The greater the mass of charred fuel that reacts, the longer it takes to increase its temperature with the same heat released. The issue of ensuring a stable combustion intensity in downdraft gasifiers that run on plant biomass requires an in-depth experimental study with the subsequent development of mathematical models that will link the design parameters of the gasification chamber with the physical and chemical properties of the fuel and the needs for syngas of the heat engineering equipment that runs on it.

The authors of [19] note that it is the high speed of blow gases at the exit of tuyeres that is the main factor that improves the flexibility of the gasification and the quality of the produced syngas. However, the study [19] also indicates that an increase in this velocity contributes to an increase in the resistance in the gasifier and attenuation of the gasification. When an internal combustion engine runs on such a gas, there is a deterioration in its filling and a drop in power, which is also confirmed by research carried out in [15]. Therefore, for each type of fuel, there is a certain limit to the appropriate increase in the speed of blow gases, which must be determined accordingly.

A promising method for increasing the calorific value of syngas to 9-13 MJ/nm^3 is the use of air-steam blow upon gasification [20]. However, research on the use of steam in the syngas production is performed mainly in gasifiers with updraft gasification and in pseudofluidised bed gasifiers running on coal. The disadvantage of this technology is the need for preliminary pair formation, which in turn is accompanied by additional capital expenditures for the purchase of appropriate equipment.

The study [21] notes that it is more expedient to intensify the gasification in a downdraft gasifier by supplying air to the gasification zone in two stages. The authors investigated the chemical composition and calorific value of syngas produced from biomass by changing the air flow rate during the gasification from 18 nm^3/h up to 22 nm^3/h and the air flow ratio in the two stages between 0% and 80%. According to the results of the study, syngas with a low resin content of 54.25±0.66 mg/nm^3 and particulate matter 102.4±1.09 mg/nm^3 were obtained, for a total air flow rate of 20±0.45 mg/nm^3 and an air ratio, between the two stages, of 80%. Thanks to the use of two-stage air supply to the gasification zone, the resin content in the produced syngas decreased by almost 87%. The results obtained in [21] should be considered upon designing the unit for preliminary preparation and supply of blow gases to the gasifier. The authors of [22] propose to use oxygen blow, which allows increasing the calorific value of syngas produced in downdraft gasifier to 11…15 MJ/nm^3. However, this technique has not been widely used commercially due to the high cost of equipment for preliminary preparation and storage of oxygen.

The influence of the air injection rate on the syngas production process is studied in the paper [23]. The gasification conditions of solid waste and wheat straw in a laboratory-scale continuous fluidised bed reactor in a high-oxygen environment are presented. The equivalence coefficient was 0.2…0.5, and the operating temperature in the gasification zone was 600…90^{0}C. To control the distribution of temperature fields in the gas reactor and the composition of the gaseous product yielded, the fuel supply and the amount of air required

for gasification were modified. The study proves that the temperature distribution in the reaction zones is controlled by the air supply, and the composition of the gas yielded is controlled by the equivalence coefficient of reagents (biomass and air). The results of this study are generalised and can be used to develop the gas-air regime of the gasification and the tuyere belt design.

There are several studies described in [5; 7; 15; 22], which note the influence of the chamber design on the gasification conditions, as well as features of the tuyere belt design to ensure proper gas blow regime. In particular, the optimal ratio of the diameter of the gasification chamber to the neck; rational geometry of tuyeres (profile, diameter, length) and their number are presented. The axial and radial characteristics of the tuyeres, the hydraulic resistance created by the tuyeres, the aerodynamics of the air current coming out of the tuyere, etc. are studied as well. Even though the presented studies provide an in-depth analysis of the influence of the gas blow regime on the nature of the gasification, the question of the dependence of the produced syngas quality on the coverage of the chamber neck with tuyere zones created by blow gas currents and the dependence of the geometry of tuyere zones on the design of the chamber has not been considered.

One of the essential features of a fuel (along with humidity, reactivity, chemical composition), which determines the chemical composition, calorific value and final application of syngas, is the size of its particles. The authors of the study [24] experimentally confirmed that the size of fuel particles substantially affects the duration of gasification, and, consequently, the size and geometry of the main components of the gasifier – hopper, chamber, etc. However, the published studies did not consider the effect of void ratio of the bulk biomass layer on the gasification. A clear understanding of the degree of influence of this parameter will allow determining as accurately as possible, depending on the volume of fractional voids of fuel, the amount of blow gases required for the gasification and the rational correlation between the amount of air and fuel.

The efficiency of syngas production from biomass in the presented studies has been investigated separately for each of the indicators – according to the calorific value of syngas, and, less frequently, according to its quantity. Studies that determine the efficiency of syngas production from biomass according to the heat quantity received from the utilisation of this gas produced during the gasifier operation cycle have not been conducted. The dependence of this indicator on the design and technological parameters of the gasifier and the properties of biomass also received no prior coverage. Therefore, to increase the efficiency of the chemical and thermal conversion of plant biomass into combustible gas, a complex of studies should be carried out using the achievements of modern scientific thought and methodology.

MATERIALS AND METHODS

The working hypothesis of this study notes that with a certain increase in the amount of blow gases entering the gasifier, the calorific value of syngas may slightly decrease, but the total amount of gas produced during the gasifier operation cycle increases. This leads to an increase in the total heat quantity received from the utilisation of such syngas, namely by its direct combustion.

Crushed wheat straw was used as the test material. The chemical composition of wheat straw per its dry weight is as follows: N=0.54%, C=43.43%, H=5.86%, O=44.26%, S=0.11%, ash content 5.8%. A polyfraction mixture is made from straw-sections as follows: small split stems with a length l=9-27 mm, wall thickness δ=0.16-0.26 mm; flattened stems – l=18-38 mm, δ=0.32-0.48 mm; cylindrical smooth stems – l=22-40 mm, δ=0.22-0.34 mm, outer diameter Ø2-4 mm; cylindrical stems – $l\approx$38 mm with thickenings, δ=0.45-1.2 mm; small split stems – $l\approx$9 mm, δ=0.15 mm; the content of other fractions in the mixture does not exceed 4%. The humidity of the straw based on which the polyfraction composition was created was 12%.

The composition of the mixture is expressed by the percentage of fractions: coarse (l>32 mm), medium (27≤l≤32 mm), and fine (l<27 mm). Mixture I contains 60% coarse, 25% medium, and 15% fine fractions and has a void ratio ε=50%. Mixture II contains 40% coarse, 45% medium, and 15% fine fractions and has a void ratio ε=43.5%. Mixture III contains 25% coarse, 60% medium, and 15% fine fractions and has a void ratio ε=30%. The content of fractions in the mixture was selected according to the reduction theory and filtration theory [15] to ensure the flow of all reactions of the gasification in the appropriate time intervals and at the specified speed. Void ratio ε of the bulk biomass layer was determined according to the method [25].

To run experiments, a pilot plant with a downdraft gasifier was designed, the flow chart of which is presented in Figure 1. The productivity of downdraft gasifier is 60-68 $m^3 \cdot h^{-1}$. The prototype for this unit was the design of the gasifier presented in [7]. According to Figure 1, the plant contained a gasifier; a unit for preparing and supplying blow gases to the gasification chamber; a unit for preparing syngas for utilisation; a unit for collecting, analysing, and accumulating data on the parameters of the syngas produced; syngas utilisation unit.

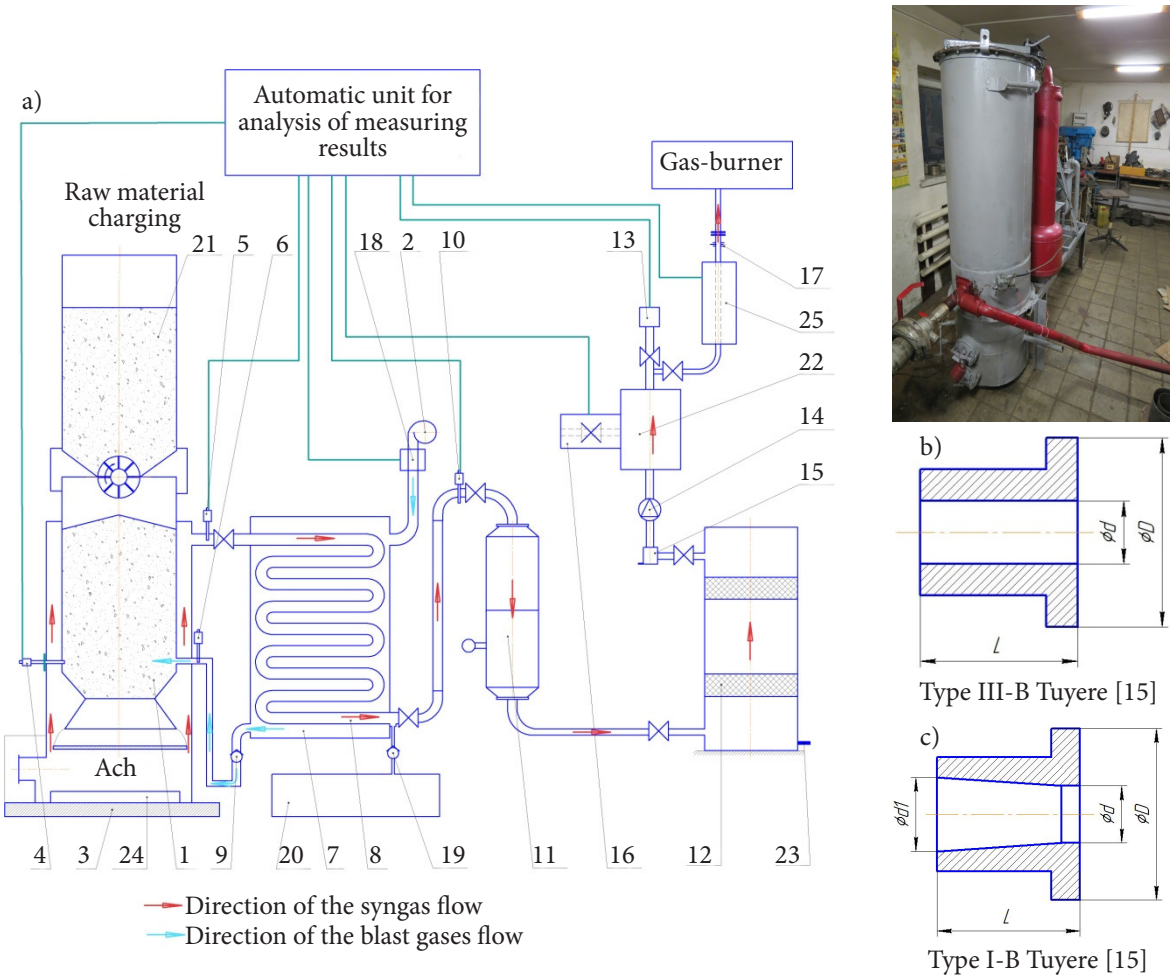

***Figure 1**. A pilot plant with a downdraft gasifier: a – the flow chart; b – downdraft gasifier; c – blowing tuyeres*

Gasification unit included a downdraft gasifier 1 equipped with a hopper with a continuous fuel supply system 21. The gasifier is installed on scales 3 (TVE 500-10 "Tekhnovahy" under DSTU EN 45501), which were used to control fuel consumption. The ash residue was weighed using laboratory scales 24 (TVE 150-5 under DSTU EN 45501). Continuous measurement of the weight of the gasifier allowed monitoring the degree of fuel burnout and coordinating the operation of the gasifier with fuel metering equipment. The temperature in the gasification zone was controlled by thermocouples 4 and 6 (tungsten-ranium thermocouples, TVR-251).

Unit for preparation and supply of blow gases to the gasification chamber. The volume of air supplied to the chamber was regulated by changing the fan rotor 2 rotation speed. The air, before being fed to the tuyere belt of the gasification chamber mounted on the gasifier 1, had been preheated to a temperature of 270…320^{0}C. Heating was carried out in the heat exchanger 7 due to the heat of the produced syngas, which, in turn, was cooled to a temperature of 40^{0}C. The temperature of the heated air was monitored by a thermocouple 6 and recorded in real time by *a block for collecting, analysing, and accumulating data*. To prevent the return of air from the tuyere zone to the heat exchanger, a non-return valve 9 is installed. The volume of air that was supplied to the gasification chamber was calculated using the meter 18.

The preparation unit for syngas utilisation was used for cleaning, cooling, and normalising the parameters of the syngas produced before utilisation in the appropriate heat engineering equipment. The unit contained a heat exchanger 7 with a coil 8, through which syngas was passed. To remove condensate developed during cooling of the syngas upon passage through the coil 8, the heat exchanger 7 was equipped with a branch pipe 19 for discharge and a tank 20 for collecting condensate. The temperature of the syngas at the inlet and outlet of the heat exchanger 7 was controlled by thermocouples 5 and 10 (chromel-aluminum, TXA-XA-2388 065-16).

The preparation unit for syngas utilisation included filters for gas purification: coarse 11 and fine 12. The branch pipe 23 in the design of the fine filter 12 served to remove condensate. The purified syngas, passing through an additional moisture separator 15, entered the receiver 22, where the gas composition was averaged within the volume of the receiver. Through the branch pipe 16, the gas was sampled to analyse the content of resins and particulate matter. To overcome the aerodynamic drag

exerted by the filter equipment, a suction-type vacuum pump 14 is provided in the gasifier design. The duration of experiments was recorded using an electronic clock with a timer. The data collection, analysis, and accumulation unit, apart from thermocouples 4, 5, 6, 10, and meter 18, included a gas calorimeter 13 (model CM6G, margin of error 1%) and a gas rotary meter 25 (RG-100 TU U 3.48-05782912-048-97, margin of error 1%).

Syngas utilisation unit contained a burner with a throttle valve 17 to control the amount of syngas supplied for utilisation. According to the task of the study, the heat quantity Q_V was measured, which can be received by recycling syngas produced during the gasifier operation cycle, and Q_V depends on the blow coverage quality coefficient k, the void ratio of the bulk biomass layer ε and the amount of air V_{air} necessary for the gasification. To link the independent (k, ε, V_{air}) and dependent (Q_V) factors, determine the nature of this link and find a mathematical equation to describe it, a multi-factor experiment was conducted using the methodology described in [26].

The total air consumption for the gasification was calculated according to [15], based on the nominal gasifier capacity for gas of 60...68 m³/h and they were 34...46 m³/h. Since the plan of the multi-factor experiment provided for three levels of variation and the intervals between levels should be the same, the values of total air flow were adopted as follows: V_{air} 30, 40, and 50 m³/h. The values of the void ratio ε of the bulk biomass layers were 35%, 43.5%, and 50%.

Coefficient k of the blow coverage quality was established analytically according to the methodology developed by the authors. Calculations were performed using the Statistica 11.0 software package (StatSoft, USA). Coefficient k was established based on the condition that the radius $\rho(S)$ of the tuyere zone may vary. The main control parameters are as follows: the speed of blow gases (air) V_{air}; tuyere specifications defined by the tuyere diameter d_t and coefficients α and a; geometric parameters of the chamber – diameter of the tuyere installation D_{ti}, neck diameter d_n, distance from tuyere belt to neck h_n. Of particular importance is ρ_{max} — the radius of the tuyere zone in the neck plane, m.

According to the theory of a turbulent source [15] applied to a current symmetric relating to the axis, the velocity of the main part of the current of blow gases will be equal to:

$$V_x = \frac{0.96 \cdot V_0}{\frac{2 \cdot a \cdot S_x}{d_t} + 0.29} = \frac{0.96 \cdot V_0 \cdot d_t}{2 \cdot a \cdot S_x + 0.29 \cdot d_t} \quad (1)$$

where V_x is the particle velocity of the blow gas current at a given point at a distance X from the tuyere nose, m/s; V_0 is the initial velocity of a current particle of blow gases at the time of exit from the tuyere nose, m/s; S_x is the distance travelled by a particle of the blow gas current from the tuyere nose to a given point on the x axis, m; d_t is the tuyere diameter, m; a is the experimental coefficient that depends on the flow structure in the initial section of the current (for a current with a circular cross-section a=0.07-0.08) [15].

When the tuyere diameter d_t decreases, the denominator of expression (1) increases, and the velocity V_x, accordingly, decreases, provided that V_0=*const*. Consequently, as the tuyere diameter increases, the range of the current increases. According to the aerodynamics of blowing in the gasification chamber, it is preferable to use a small number of tuyeres of a larger diameter. Since there is a tendency to a sharp decrease in the speed of the blow gas current V_x along the x-axis, the limit values of the parameter V_x, are set, upon reaching which the movement of the gas flow towards the x axis stops. Evidently, $V_X << V_0$, and $V_X << V_Z$.

The initial velocity of blow gases in the tuyere nose is as follows:

$$V_0 = \frac{4 \cdot V_{air}}{\pi \cdot \alpha \cdot n \cdot d_t^2} = \frac{5.06 \cdot N_2^{\varepsilon} \cdot V_{gas}}{\pi \cdot \alpha \cdot n \cdot d_t^2} \quad (2)$$

where α is the current compression coefficient, which determines the ratio of the area of the smallest cross-section of the current to the area of the tuyere opening in its smallest cross-section (α=0.7-1.3) [15]; n is the number of tuyeres; V_{air} is the air consumption for the gasification, m³/h; V_{gas} is the volume of syngas produced, m³/h; N_2^{gas} is the nitrogen content in syngas, which depends on its content in straw and in blow gases supplied to ensure the gasification (N_2^{gas}=0.38...0.53 of mass fraction).

Therefore, considering (2), the velocity of the main part of the blow gas current is as follows:

$$V_x = \frac{1.54 \cdot N_2^{\varepsilon} \cdot V_{gas}}{\alpha \cdot n \cdot d_t \cdot (2 \cdot a \cdot S_x + 0.29 \cdot d_t)} \quad (3)$$

Under different conditions, the tuyere zones created by blow gas currents in the chamber neck may undergo coverage to varying degrees. As an example, three variants of schemes for tuyere zones coverage in the neck of the gasification chamber with the number of tuyeres n=8 are considered (Fig. 2). According to Figure 2, three main zones of fuel coverage with a gas current are formed in the cross-section of the neck: Zone 1 – a single coverage; Zone 2 – the zone that is not covered by any of the currents (phenomena of insufficient CO_2 content in the gas mixture are observed, or low recovery intensity); zone 3 – a zone where two or more gas currents undergo coverage. Consequently, on the one hand, there is a more intense mixing of gas, and on the other hand, there may be a lack of carbon in the fuel, which affects the quality of syngas. The key factor for justifying rational blow parameters is to plan a coverage scheme that will provide the highest calorific value of syngas at a given gas chamber capacity. Therewith, the values of the neck diameter and the radius of the tuyere zone are not important, only their ratio affects the gasification conditions.

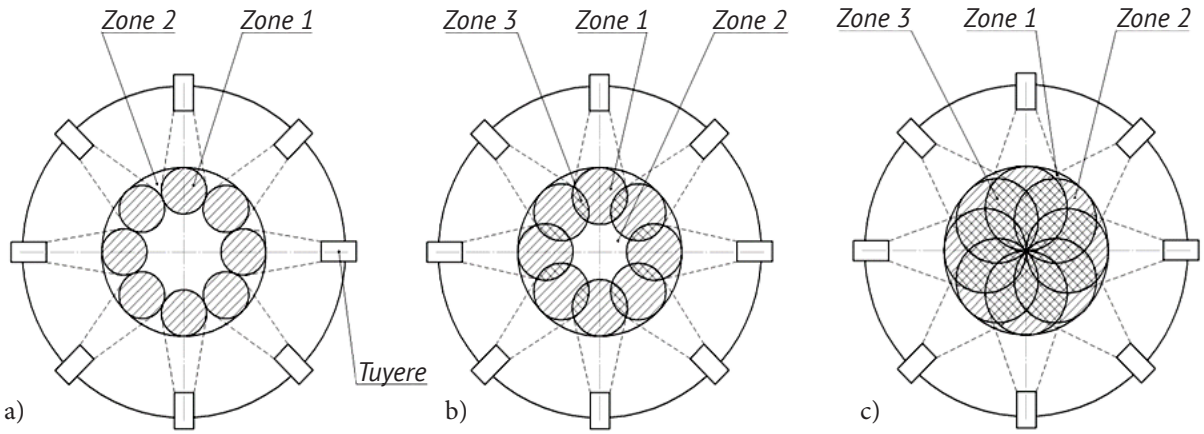

Figure 2. *Schemes for tuyere zones coverage created by blow gas currents in the neck of the gasification chamber depending on their radii ρ(S) with the number of tuyeres n=8:*
a) coverage of cross-sections of tuyere zones in the chamber neck at $(d_n / 2 \cdot \rho_{max}) = 3.6$;
b) coverage of cross-sections of tuyere zones in the chamber neck at $(d_n / 2 \cdot \rho_{max}) = 2.75$;
c) coverage of cross-sections of tuyere zones in the chamber neck at $(d_n / 2 \cdot \rho_{max}) = 2$

To compare the gasification conditions, the specific area of the coverage calculated for the number of tuyeres n=8-12 was investigated. The specific area of the coverage is determined considering the coefficient k, which for Zone 1 is k=1, for Zone 2 – k=0.2, for Zone 3 – k=0.6. Based on the research results, graphical dependencies were constructed (Fig. 3).

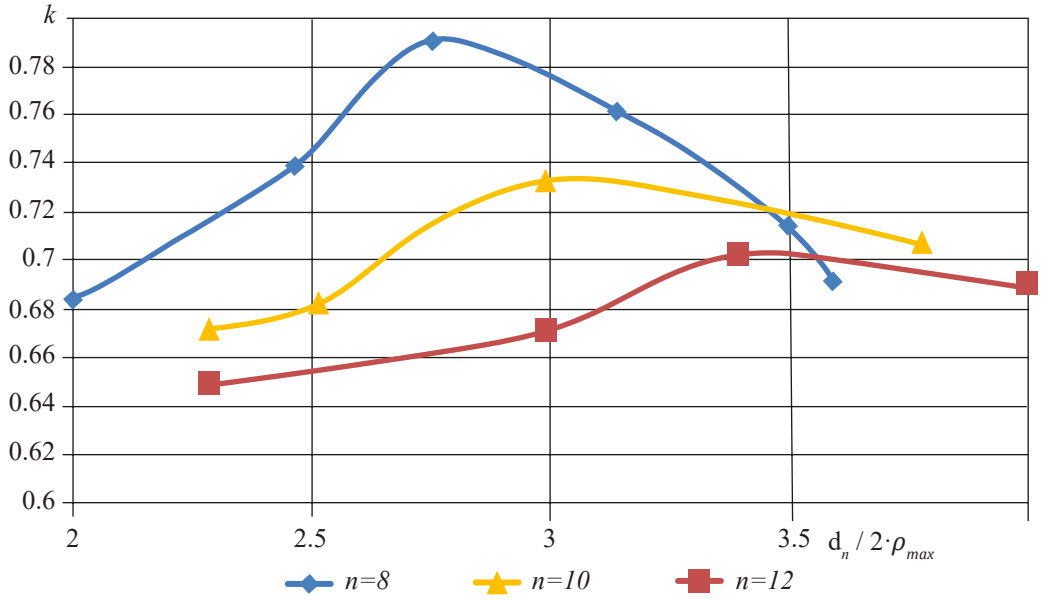

Figure 3. *Dependence of the coverage quality coefficient k from the number of tuyeres n and the correlation* $(d_n / 2 \cdot \rho_{max})$

The result of the study (Fig. 3) is the establishment of the conditions that are most favourable for the gasification, with certain correlations between the neck diameter d_n and the opening radius of the tuyere zone in the neck section ρ_{max}. Thus, with the number of tuyeres n=8, the best conditions for the gasification are achieved when $d_n / 2 \cdot \rho_{max}$=2.75 (while k = 78%). With the number of tuyeres n = 12, these conditions are achieved when $d_n / 2 \cdot \rho_{max}$=3.39 (k=70.5%).

These findings suggest that it is more appropriate to use a smaller number of tuyeres, while providing the ability to control the path that the blow gas currents pass in the chamber. The justified correlations $(d_n / 2 \cdot \rho_{max})$ are summarised in Table 1.

***Table 1**. Influence of the number of tuyeres and the radius of the tuyere zone in the neck section on the path of the blow gas current along the x axis*

No.	Number of tuyeres n, pcs.	Radius of the tuyere zone in the neck plane ρ_{max}, m	Coefficient of the blow coverage quality in the chamber neck by tuyere zones created by air currents k
1	8	$\rho_{max}=d_g/5.5$	0.68...0.78
2	10	$\rho_{max}=d_g/5.98$	0.67...0.73
3	12	$\rho_{max}=d_g/6.78$	0.65...0.71

To conduct the experiment, a five-level second-order plan was implemented according to the methodology described in [26]. The plan for conducting experiments made provision for a variation of three independent factors k, V_{air} and ε, which affect the heat quantity Q_V, which can be received from the utilisation of syngas. Factors encoding: $X_1=k$, $x_2=V_{air}$, $X_3=\varepsilon$.

Variation levels of abovementioned factors are presented in Table 2.

***Table 2**. Variable factors and limits of their variation for definition of heat quantity that can be received from syngas burning, which was produced during one-hour gasifier operation cycle*

Factor variation level	Coefficient of blow coverage quality k	Blow gases volume V_{air}, m³·h⁻¹	Void ratio of bulk biomass layer ε, %
Lower level (-)	0.68	30	35
Middle level (0)	0.74	40	42.5
Upper level (+)	0.8	50	50

The first step of the study (Table 3) investigated the polyfraction mixture II, with void ratio of the bulk biomass layer ε 43.5%. The tuyere belt contained 8 tuyeres Ø10.6 mm each with a nozzle of the corresponding design (Type I-B). According to the design of the tuyere belt and the void ratio of the bulk biomass, the coefficient k was 0.8. Through the tuyeres, air was supplied to the gasification zone with a volume of V_{air}=50 m³/h and the amount of syngas produced and its calorific value were measured. The heat that can be obtained by burning the produced syngas was calculated as follows. The experimental interval, which was one hour, was divided into elementary intervals of 4 minutes. Time intervals were recorded by an electronic clock with a timer integrated into the data collection, analysis and accumulation unit. At the specified time intervals, the indicators of the gas meter 18 and the indicators of the gas calorimeter 13 were recorded. The heat was defined as the sum of the products of the volumes of gas produced in an elementary time interval and the calorific value of this gas.

The implementation of a multi-factor experiment involved the following actions: encoding factors; randomisation; developing a sequence of experimental stages; establishing the degree of reproducibility of the experiment; determining and evaluating the significance of regression coefficients; establishing the adequacy of the model. A series of 15 original experiments was performed according to the planning matrix and the coefficients of the linear part of the polynomial were calculated using the methodology described in [26]. For the reliability of experimental data, it is assumed that the number of parallel experiments conducted under the same conditions is equal to three.

***Table 3**. Diameters and types of tuyeres that provide the volume of air for gasification and the blow coverage quality coefficient for the corresponding values of void ratio of the bulk biomass layer*

	Experiment planning method			Values of experimental factors			Tuyere diameter d_t, mm	Tuyere type [15] (Fig. 1)
	X_1	X_2	X_3	X_1	X_2	X_3		
1	+	+	0	0.8	50	43.5	10.6	I-B
2	+	–	0	0.8	30	43.5	7.4	III-B
3	–	+	0	0.68	50	43.5	10.4	III-B
4	–	–	0	0.68	30	43.5	9	I-B

Table 3, Continued

	Experiment planning method			Values of experimental factors			Tuyere diameter d_t, mm	Tuyere type [15] (Fig. 1)
	X_1	X_2	X_3	X_1	X_2	X_3		
5	0	0	0	0.74	40	43.5	8.8	III-B
6	+	0	+	0.8	40	50	9.2	III-B
7	+	0	–	0.8	40	35	7.8	III-B
8	–	0	+	0.68	40	50	10	III-B
9	–	0	–	0.68	40	35	9.4	I-B
10	0	0	0	0.74	40	43.5	8.8	III-B
11	0	+	+	0.74	50	50	10.6	III-B
12	0	+	–	0.74	50	35	9	III-B
13	0	–	+	0.74	30	50	9.2	I-B
14	0	–	–	0.74	30	35	7.8	I-B
15	0	0	0	0.74	40	43.5	8.8	III-B

According to the plan of multifactor experiment, the values of the model's relative error are lower than 1.64%. This is the case for all experiments. The values of mean relative deviation are lower than 1.2%. Thus, the relative error value is less than 5%. Such relative error value is considered acceptable in modelling [26].

Therefore, it can be concluded that presented model predicts the heat quantity (that can be received from syngas burning, which was produced during one-hour gasifier operation cycle) with high accuracy.

RESULTS AND DISCUSSION

The results of the experimental study were processed using the Statistica package. As a result of experimental research and statistical processing, an array of data values of the heat quantity Q_V was obtained, which is received from the utilisation of syngas produced during the gasifier operation cycle, which are presented in Table 4.

***Table 4**. Calculated matrix of the heat received from the utilisation of syngas produced during the gasifier operation cycle*

No.	Experiment planning method				Experiments results				Model adequacy check		
	X_0	X_1	X_2	X_3	Q_{V1}	Q_{V2}	Q_{V3}	$Q_{V\,med}$	$Q_{V\,med.com}$	$(Q_{V\,med} - Q_{V\,med.com})$	$(Q_{V\,med} - Q_{V\,med.com})^2$
1	+	+	+	0	516.9	512.0	512.0	513.6	508.9	4.7	22.129
2	+	+	–	0	411.0	409.0	407.0	409.0	400.9	8.1	64.870
3	+	–	+	0	474.0	474.0	473.0	473.7	481.7	-8.1	64.870
4	+	–	–	0	300.0	298.0	299.0	299.0	303.7	-4.7	22.129
5	+	0	0	0	468.0	471.0	467.0	468.7	470.6	-1.9	3.568
6	+	+	0	+	435.0	437.0	438.0	436.7	445.0	-8.4	69.931
7	+	+	0	–	399.0	399.0	393.0	397.0	402.7	-5.7	32.443
8	+	–	0	+	413.0	412.0	408.0	411.0	405.3	5.7	32.443
9	+	–	0	–	326.0	327.0	326.0	326.3	318.0	8.4	69.931
10	+	0	0	0	469.0	472.0	472.0	471.0	470.6	0.4	0.198
11	+	0	+	+	490.0	493.0	490.0	491.0	488.9	2.1	4.340
12	+	0	+	–	356.0	354.0	355.0	355.0	355.6	-0.6	0.340
13	+	0	–	+	279.0	277.0	278.0	278.0	277.4	0.6	0.340
14	+	0	–	–	281.0	277.0	279.0	279.0	281.1	-2.1	4.340
15	+	0	0	0	470.0	476.0	470.0	472.0	470.6	1.4	2.086

Regression coefficients: b_0=470.556; b_1=31.113; b_2=71.5; b_3=32.417; b_{12}=-17.508; b_{13}=-11.25; b_{23}=34.25; b_{11}=-2.365; b_{22}=-44.365; b_{33}=-75.44.

The Cochran's test was applied to verify the uniformity of variances. The tabular value of the Cochran's test criterion was G^{table}=0.4 at 5% significance levels for the number of degrees of freedom equal to f_2=2 and the number of experiments f_1=15. It was established that G^{com}=0.21<G^{table}(0.05; 15; 2)=0.4 [26]. Thus, the process is fully reproduced.

The significance of the coefficients of the regression equation is estimated according the Student's t-test. Tabular value of the Student's t-test at 5% significance level, f_2=2 and the number of experiments f_1=15 was t=4.3 [26; 27]. The coefficients of the regression equation were estimated by their significance and insignificant ones were excluded. Finally, the polynomial equation took the following form:

$$Q_V=470.556+31.113\cdot X_1+71.5\cdot X_2+32.417\cdot X_3-17.508\cdot X_1\cdot X_2-11.25\cdot X_1\cdot X_3+34.25\cdot X_2\cdot X_3-2.365\cdot X_1^2-44.365\cdot X_2^2-75.44\cdot X_3^2 \quad (4)$$

where Q_V is the heat quantity received from the utilisation of syngas produced during one hour gasifier operation cycle, MJ/h; X_1 is the encoded value of the coefficient of the blow coverage quality for the neck cross-section in the gasification chamber by air currents of the tuyere zone; X_2 is the encoded value of the air supply for gasification, m^3/h; X_3 is the encoded value of the void ratio of the bulk biomass layer.

The hypothesis on the adequacy of the model to the object under study was tested using the Fisher's test. Variance $S_y^2\{Q_V\}$ of the initial optimisation parameter was established based on the results of experiments in the centre of the plan (Table 4) and amounted to S_y^2=2.92. As a result of calculations, the value of the adequacy variance was obtained, which was equal to S^2_{inadeq}=2.77. The calculated value of the Fisher's test for the specified values of variances was equal to F^{com}=9.47. Since F^{com}=9.47<F^{table}(0.05; 15; 2)=19.38, then the hypothesis on the adequacy of the regression equation is confirmed [26; 27]. The value of the coefficient of determination was R^2=0.983. Thus, the mathematical model (4) of the parameter Q_V dependence obtained from variable factors adequately describes the results of the experiment at a 5% significance level.

After substituting the values of the obtained coefficients into canonical Equation (4), the regression equation of the process under study is written as follows:

$$Q_V=-4748.56+3720.53\cdot k+44.83\cdot V_{air}-118.55\cdot\varepsilon-29.18\cdot k\cdot V_{air}-25\cdot k\cdot\varepsilon+0.457\cdot V_{air}\cdot\varepsilon-656.944\cdot k^2-0.444\cdot V_{air}^2-1.341\cdot\varepsilon^2 \quad (5)$$

where: Q_V is the heat received from the utilisation of syngas in the volume produced by the gasifier during the one-hour operation cycle, MJ/h; k is the coefficient of the blow coverage quality; V_{air} is the air supply for gasification, m^3/h; ε is the void ratio of the bulk biomass layer, %.

Graphical representations of the abovementioned equation are presented in Figure 4-b.

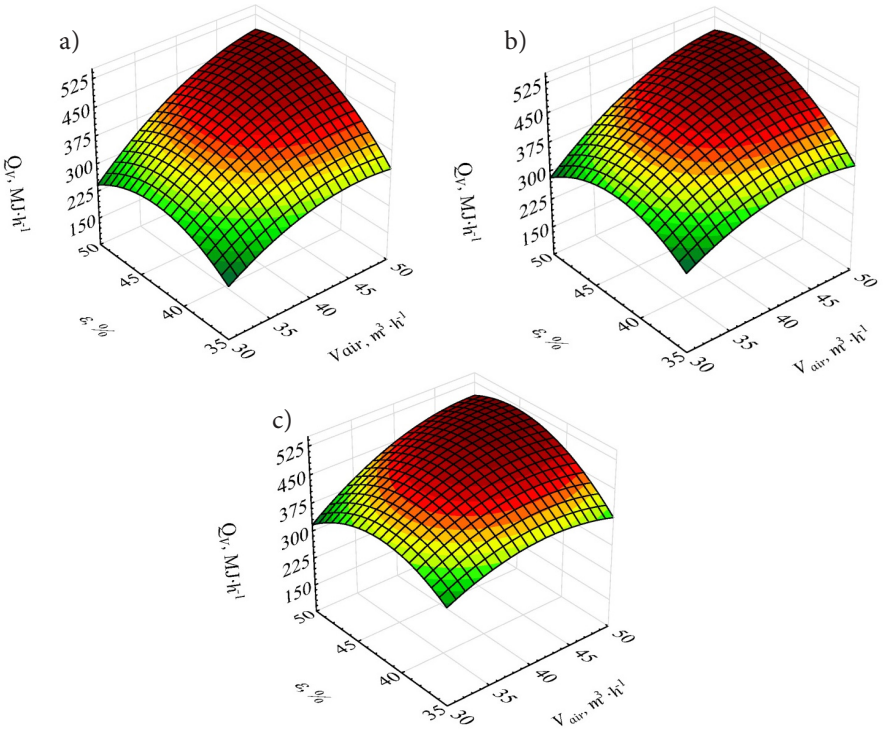

***Figure 4**. Dependence of the heat quantity Q_V on the void ratio of the bulk biomass layer ε and air supply for gasification V_{air}: a) – k=0.68, b) – k=0.74, c) – k=0.8*

According to Figure 4a, the dependence of the heat quantity Q_V from void ratio ε and the volume of air blow V_{air} is nonlinear and has a well-formed maximum observed for all values of the coefficient k. Thus, with the blow coverage quality coefficient k=0.68 and void ratio of the polyfraction mixture ε =46.7%, to reach the maximum parameter value Q_{Vmax}=502 MJ/h, it was necessary to bring 49.2 m³/h of air into the chamber for the gasification. Considering the results obtained, for the coefficient k=0.68, the recommended air blow volume range is equal to V_{air}=45.2…53.2 m³/h.

With increasing void ratio of the bulk biomass ε from 35% to 46.7%, the heat quantity Q_V also increases. This phenomenon is explained by the fact that the resistance of the fuel layer against the passage of air through it decreases. The degree of branching of the paths through which air currents pass through the bulk biomass layer also increases, which, in turn, increases the radius of opening of the currents in the cross-section of the neck of the gasification chamber. However, with a further increase in void ratio of the bulk biomass layer ε towards values above 46.7%, the heat quantity Q_V decreases. This phenomenon is explained, on the one hand, by a decrease in the contact area of the fuel surface with air, on the other hand, by the development of air currents of stable trajectories in a bulk biomass with a large void ratio. The latter, in turn, also helps reduce the contact area of the fuel surface with air. Additionally, the higher void ratio of the bulk biomass helps reduce the temperature in the core of the gasification chamber, which entails worse conditions for the main chemical reactions of the gasification and the predominance of CO_2 content over the CO content in the syngas produced.

According to Figure 4b, at the value of the coefficient k=0.74 the maximum heat quantity Q_V=514 MJ/h is achieved at a lower value of the air blow volume (V_{air}=48.3 m³/h) compared to Figure 4a. The void ratio value remains almost unchanged and is ε=46.5%. As the coefficient k increases from 0.68 (Fig. 4a) to 0.74 (Fig. 4b), the value Q_V grows, reaching Q_V=512 MJ/h at V_{air}=50 m³/h and ε=46.75%. In the above case, an increase in the heat quantity Q_V is explained by the improvement of the syngas quality. Chemical analysis of syngas demonstrated that the CO content in the gas increased from 16.25% to 19.01%. The measurements were performed at the Gas Institute of the National Academy of Sciences of Ukraine using a two-channel chromatograph model Agilent 6890 N.

The graphical dependency presented in Figure 4b, was built at the highest value of the blow coverage quality coefficient k=0.8. Under these conditions, the volume of air blow V_{air}, at which the maximum value is obtained Q_V=519 MJ/h, reduced to 47.4 m³/h with the specified void ratio value of the bulk biomass layer ε=46.75%. The results obtained indicate that the higher values of the coefficient k, that is, the highest quality of coverage of the gasification chamber neck with air currents improves the conditions of gasification. This also contributes to an increase in the calorific value of syngas due to an increase in the CO content in the chemical composition of the produced gas.

Analysis of dependencies presented in Figure 4 indicates that the blow coverage quality coefficient k has a greater impact on changing the parameter Q_V compared to the volume of air blow $V_{air.}$ Thus, even at the lowest values of the air blow volume (V_{air}=30 m³/h), with increasing coefficient k, the parameter Q_V is also rapidly growing, especially in the range of values of void ratio of the bulk biomass layer ε =45…47%.

The surfaces presented in Figure 5 illustrate the dependence of the parameter Q_V on the void ratio of the bulk biomass layer ε and the coefficient k at the values of the air blow volume V_{air}, which are equal to 30, 40, and 50 m³/h, respectively.

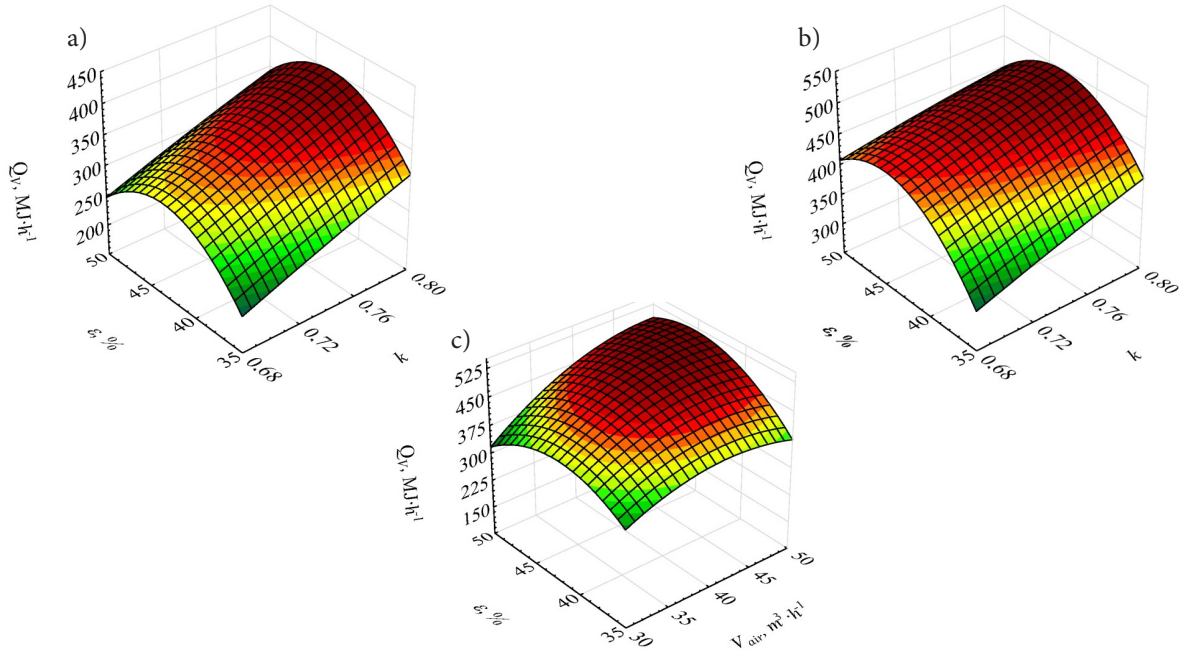

Figure 5. *Dependence of the heat quantity Q_V on the void ratio of the bulk biomass layer ε and the blow coverage quality coefficient k: a) – V_{air}=30 m³/h, b) – V_{air}=40 m³/h, c) – V_{air}=50 m³/h*

Analysis of the surfaces presented in Figure 5 indicates the existence of an optimal void ratio range for the bulk biomass layer ε, which is 45…47%. It is in this range that the highest values of the parameter Q_V are observed for all values k and V_{air}. In this case, between the heat quantity Q_V and the k coefficient there is a correlation close to linear. Increasing the value of the k coefficient leads to an increase in the Q_V parameter. In the range of optimal void ratio values ε=45…47% at k=0.68, the heat quantity Q_V is 303.7 MJ/h. When the coefficient k increases to a value of 0.8, the heat quantity reaches Q_V=401 MJ/h, i.e., increases by 65.7%. When the amount of air blow V_{air} increases in the process of gasification with a simultaneous increase in the k coefficient, the upward trend of the parameter Q_V is retained. However, with an increase in the amount of air blowing V_{air}, the growth in the heat quantity Q_V decreases.

According to Figure 5c, at the value k=0.68 in the range of the values of void ratio of the bulk biomass ε=45…47%, the maximum value of Q_V is 502 MJ/h. As the k coefficient increases up to 0.8, the heat quantity Q_V=518 MJ/h, i.e., increases by only 3.5%. This indicates a more substantial influence of the blow coverage quality coefficient k on the parameter Q_V with smaller volumes of air blow V_{air} and a reduction in the impact of this coefficient k under conditions of intensification of air blow. This can be explained by the fact that with an increase in the blow volume, the bulk biomass layer is more intensively mixed in the cross-section of the chamber neck, which, in turn, increases the contact area of air with the fuel surface.

Figure 6 demonstrates graphical dependencies that illustrate the correlation between the heat quantity Q_V, air blow volume V_{air}, and the blow coverage quality coefficient k at different values of void ratio of the bulk biomass layer ε. According to Figure 6, with an increase in the volume of air blow V_{air} up to 49 m³/h, the parameter Q_V is growing. However, with further increase of V_{air}>49 m³/h, the parameter Q_V starts to subside. Lower values of the heat quantity Q_V at V_{air}<45 m³/h indicate a lack of oxygen, which leads to incomplete carbon oxidation of the fuel. At the volume of air blow V_{air}>53 m³/h, the parameter Q_V decreases, and the fuel is cooled in the gasification zone by excess air. This process is accompanied by active carbon removal of fuel with the produced syngas, which leads to an increase in the volume of CO_2 content in syngas by reducing the CO content. According to Figure 6, the optimal parameter Q_V for the syngas production is a range of air blow volume within V_{air}=V_{air}=45.2…53.2 m³/h.

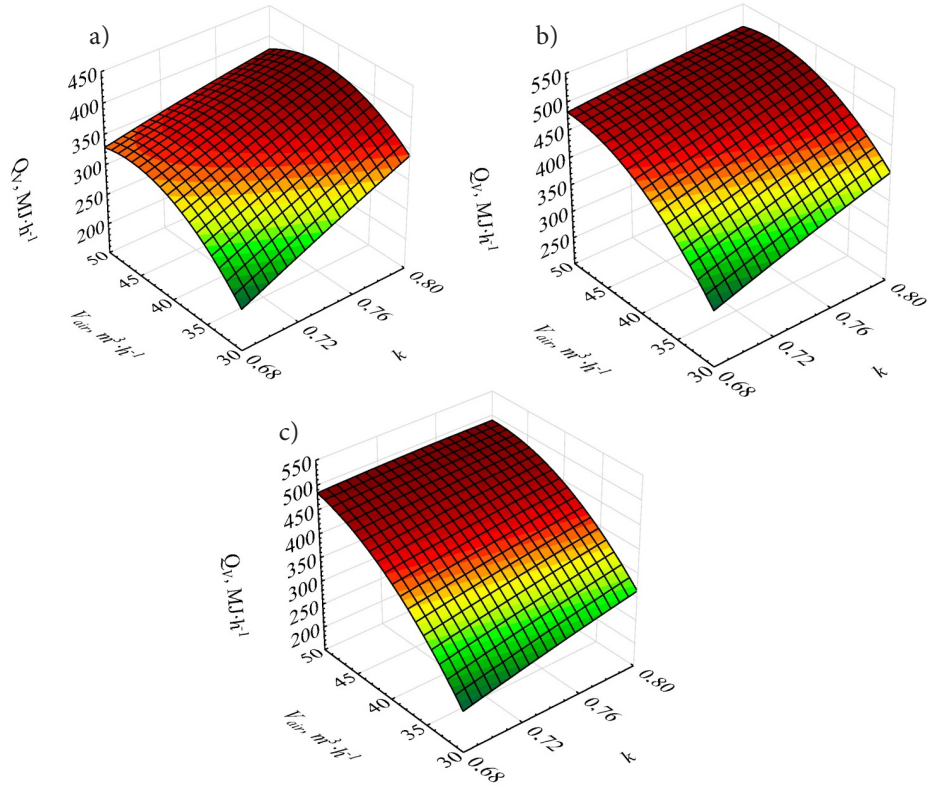

***Figure 6**. Dependence of the heat quantity Q_V from the blow coverage quality coefficient k and air supply for gasification V_{air}: a) – ε=35%, b) – ε=43.5%, c) – ε=50%*

Graphical dependencies presented in Figure 6 also indicate that with an increase in the blow coverage quality coefficient k, heat quantity Q_V of the generated syngas is also growing. In this case, the maximum value of the parameter Q_V=521 MJ/h corresponds to the void ratio of the bulk biomass layer ε=45%, air blow volume V_{air}=47.3 m³/h and the blow coverage quality coefficient k=0.8. The resulting value of 521 MJ/h is greater than the heat equal to 505 MJ/m³, which was received from the utilisation of the maximum amount of syngas produced (65 m³) with the highest calorific value of 7.9 MJ/m³.

The presence of optimal ranges of void ratio of

the bulk biomass layer in the presented study ε and the volume of air blow V_{air} suggest that, under the condition of direct utilisation of the produced syngas, such an indicator as the HHV of the syngas produced is not decisive. A more defining indicator is the heat quantity Q_V received from the utilisation of the produced syngas in the appropriate heat engineering equipment. Optimal ranges of void ratio of the bulk biomass ε and the volume of air blow V_{air} at k=0.8, where the maximum heat quantity Q_V (500…521 MJ/h) can be received from the utilisation of syngas produced from the straw section during the one-hour gasifier operation cycle are ε=45…47% and V_{air}=45.2…53.2 m^3/h, respectively.

There are several studies aimed at high-tech improvements of gasification, the design of gasifiers, etc. These studies put forward extremely bold hypotheses, the implementation of which in real projects has a high cost and technical complexity. Scientific papers [21; 28] present research results similar to the level of constructive complexity of the above experiment. These works indicate the degree of influence of air blow on the calorific value of syngas produced in a fixed bed gasifier, but the design of the main components of the gasifier, namely the gasification chamber, and the type of raw materials that are gasified differ. In the study [21], eucalyptus wood was used as a raw material. Thanks to the two-stage air supply, syngas with a low calorific value of about 5 MJ/m^3 was obtained. Even though in the present study that syngas of the highest calorific value of about 7.9 MJ/m^3 was obtained, it is incorrect to compare the results of these studies, since in the present case the studies were performed with a section of wheat straw. In addition, a hypothesis similar to that put forward in the experiment presented herein has not yet been investigated. The comparison can be carried out exclusively according to the gasifier performance indicators in terms of gas yield and average calorific value.

CONCLUSIONS

1. The design of a downdraft gasifier running on plant biomass was developed and numerous studies were performed to establish the efficiency of the gasifier according to the total heat quantity received from the utilisation of syngas produced during the gasifier operation cycle.

2. The influence of the blow coverage quality coefficient of the chamber neck with tuyere zones created by air currents, the amount of air required for the gasification, and the void ratio of the bulk biomass layer on the total heat quantity received from the combustion of syngas produced during the gasifier operation cycle is experimentally studied. The findings of the present study are as follows:

– There is an optimal range of void ratio of the bulk biomass layer based on straw cross-section wherein high values of the heat quantity 502…519 MJ/m^3 are obtained and it amounts to 45…47%. If the void ratio values of the bulk biomass layer are less than 45%, the resistance that the fuel layer exerts against the passage of air through it increases. At void ratio values over 47%, the contact area of the fuel surface with air decreases, which also leads to a decrease in the heat quantity.

– With an increase in the volume of air required for the gasification from 30 to 45 m^3/h, the heat quantity received from the utilisation of syngas increases from 280 MJ/m^3 to 512 MJ/h in the range of void ratio of the bulk biomass layer of 45…47% with the blow coverage quality coefficient k=0.74. Therewith, the heat continues to increase due to an increase in the volume of syngas produced, even if the calorific value of the gas slightly decreases. The optimal range of blow volume values required for the gasification process is 45.2…53.2 m^3/h. The maximum value of the heat is 521 MJ/h and was obtained with a void ratio of the bulk biomass layer of 45%, an air blow volume of 47.3 m^3/h and the value of the blow coverage quality coefficient of the chamber neck section by air currents k equal to 0.8.

– As the quality factor of the blow coverage increases, the heat that can be obtained from burning the generated syngas also increases. With an increase in the blow coverage quality coefficient, a larger increase in heat quantity is inherent in smaller volumes of air blow. As the blow coverage quality coefficient increases, the effect of the blow volume on the heat quantity received from the utilisation of the produced syngas decreases. Dependencies (Fig. 4-6) indicate the achievement of close maximum values of the heat quantity, which vary in the range of 500…521 MJ/h. This indicates the need to adjust the blow within the optimal range and reduces the impact of the design of the tuyere belt of the chamber (diameter and shape of the tuyere), but does not eliminate the need for their correct selection.

3. Therefore, the results of the study confirm that with an increase in the blow volume, the volume of syngas increases faster than its calorific value decreases. Therefore, the heat has a maximum shifted relative to the maximum calorific value towards increasing the blow volume. At optimal gasification modes (blow volume 47.3 m^3/h, void ratio of the bulk biomass 45%, blow coverage quality coefficient 0.8) 521 MJ/h heat was obtained from syngas utilisation. This is more than the heat quantity equal to 505 MJ/h, which was received from the utilisation of the maximum amount of syngas produced (65 m^3), the highest calorific value of which was 7.9 MJ/m^3.

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Експериментальні дослідження конструкційно-технологічних параметрів протипотокового газогенератора на рослинній біомасі

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Анотація. Актуальність дослідження обумовлена необхідністю розробки та впровадження конструкційно-технологічних рішень щодо підвищення ефективності процесу хіміко-термічної конверсії біомаси в горючий газ. У рамках зазначеного розроблено конструкцію газогенераторної установки, яка містить протипотоковий газогенератор, що працює на рослинній біомасі. Представлені дослідження пов'язують кількість теплоти, яку можна отримати при утилізації синтез-газу, виробленого за цикл роботи установки, з параметрами газодуттьового режиму та фізико-хімічними властивостями біомаси. Для поглибленого дослідження впливу газодуттьового режиму на кількість і теплотворну здатність синтез-газу, виробленого з біомаси, введено поняття коефіцієнту якості дуттьового перекриття. Даний коефіцієнт характеризує якість перекриття перерізу горловини камери газоутворення газовими струменями фурмової зони. Мета роботи полягала у встановленні впливу коефіцієнту якості дуттьового перекриття, об'єму газів дуття та порозності насипного шару біомаси на кількість теплоти, яку можна отримати при утилізації синтез-газу, виробленого за цикл роботи установки. Спланувано та проведено багатофакторний експеримент, який пов'язує залежний фактор із змінними, та побудовано відповідні поверхні відгуку. За результатами досліджень встановлено, що максимальне значення кількості теплоти, отриманої при утилізації синтез-газу, виробленого за годинний цикл роботи установки, становило 519 МДж. Дане значення досягається при коефіцієнті якості дуттьового перекриття 0,8, об'ємі газів дуття 47,4 м^3/год та порозності насипного шару біомаси 46,75 %. Результати вимірювань мають високу відповідність розрахунковим даним. Коефіцієнт детермінації становив R^2=0,983. Практична цінність дослідження полягає в обґрунтуванні раціональних конструкційно-технологічних параметрів роботи протипотокового газогенератора на біомасі, що дозволить підвищити ефективність виробництва енергії з біомаси. Отримані результати можуть бути використані як для створення конструкцій нових газогенераторних установок, так і для підвищення ефективності роботи вже наявних

Ключові слова: протипотоковий газогенератор, камера газоутворення, синтез-газ, фурмовий пояс, порозність, коефіцієнт якості дуттьового перекриття

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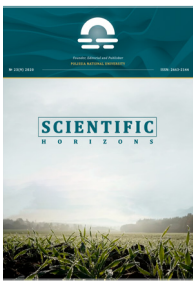

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Determination of Length of Individual Pellets and Pellets' Lengths Distribution

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Abstract. A form and dimensions of fuel particles influence the intensity of their burning and approaches to the mathematic description of the process. Known methods do not allow correctly measuring all pellets' lengths and describing pellets' lengths distribution. The purpose of the study is to substantiate method for determining the individual pellet length and to specify statistical characteristics of pellets' lengths distribution. The purpose was achieved by applying the proposed method of indirect determination of the length of each pellet by weighing it, followed by calculation of the equivalent length and modal cluster analysis of the distribution of pellets by length, based on the probability density distribution. The most noteworthy results are that the experimental calculation of the equivalent length gives results that coincide with direct measurements for pellets of the correct shape, but in contrast to direct measurements can also be used to determine the equivalent lengths of irregularly shaped pellets and their fragments. Clustering allowed grouping pellets around objectively existing local maxima in the probability density distribution, which can be identified at intervals of pellet lengths not exceeding 2 mm. The importance of the obtained results is that the indirect method of determining the length of pellets allows replacing the measurement of pellet lengths by their weighing, which eliminates subjective factors when measuring the length of irregularly shaped pellets and their fragments. Clustering characterised the granulometric composition of pellets with histograms of probability, mass fraction, and average length by clusters. Upon using proposed approaches, granulometric composition of industrially produced pellets was specified and increased probabilities were noted for 8 mm pellets in clusters of smaller lengths, compared to 6 mm pellets; while straw pellets are characterised by a higher probability in clusters with shorter lengths compared to wood pellets

Keywords: pellets, length measurement, length determination, probability density distribution, clustering, histograms, pellets lengths distribution

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INTRODUCTION

A considerable part of the territory of Ukraine is located in the steppe zone with intensive grain production, so the energy use of cereal straw is promising, the annual resources of which, according to various estimates, amount to more than 10 million toe. According to the authors of this study, in 2020, in Ukraine, boilers with periodic burning of whole bales consumed up to 20,000 tons of straw. An alternative approach may be to produce pellets from straw and use them as fuel. Pellets are more convenient and safer for transportation and storage, allow achieving complete mechanisation and automation of processes.

The combustion of wood pellets in a stationary bed has been studied in detail, and the technologies of their combustion in retort burners or on moving grates have reached technical perfection [1-3]. Attempts to burn straw pellets instead of wood pellets in retort burners and burners with moving grates led to agglomeration of ash due to low temperature characteristics of its melting, to disruption of work with a considerable decrease in heat output and energy efficiency, increased *CO* emissions [4; 5]. These obstacles necessitated more detailed studies on the differences in the properties of wood and straw, differences in their combustion processes. Many papers are devoted to the study of the composition of the mineral part of wood and straw, transformations of the mineral part during the formation of ash, temperature characteristics of its melting [6-8].

The size and shape of fuel particles also affect the combustion process. When considering the combustion of single particles, they usually took their spherical shape, which allow simplifying the mathematical model to a one-dimensional one. In [9], it is shown that when the particle size is more than a few tenths of a millimetre, the spherical approximation unsatisfactorily reflects the features of combustion. In [10], a mathematical model of thermal conversion of biomass particles is described, which considers their shape and size. In [11], it was experimentally found that at the same mass, cylindrical particles lose mass faster than spherical ones, and it is believed that the duration of their complete burnout decreases with increasing surface area. The importance of the proper granulometric composition of pellets is indicated in [12; 13] and it is noted that the presence of small particles can affect the processes of storage, supply, combustion efficiency, and emission of pollutants. General requirements for the granulometric composition of pellets are established by the standard [14]. Pellets can be produced in nominal diameters of 6, 8, 10, 12, and 25 mm with particle lengths up to (40 ... 45) mm. Within the same class of pellets, their actual diameter may differ by ±1 mm in diameter [14-16].

According to the content of small particles, pellets are divided into 7 classes with a fine content from 1 to 6 and more than 6% by weight. The content of small particles should be determined by sieving with holes with 3.15 mm diameter round holes [17]. For non-industrial (domestic and equivalent) wood pellets, the content of fine particles is limited to 1% [15]. For non-wood pellets (including straw pellets), the content of small particles is limited to (2 ... 3)% by weight [16].

The length and diameter of pellets should be measured with a calliper with a resolution of at least 0.1 mm, and the average length and average diameter of pellets should be rounded to 0.1 mm. In addition, it is necessary to determine the standard deviation of the length, the mass fraction of pellets less than 10 mm long in the test portion [18], selected and prepared in accordance with the standards [19; 20]. In the standard [18], by default, it is accepted that pellets have the cylindrical shape with a convex protrusion at one end and depression at the other, while the length of the pellet is usually measured manually with a calliper as the distance along its axis from the top of the protrusion to the end with a depression (Fig. 1). In this study, this form of pellets is generally called correct.

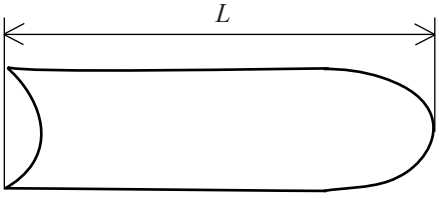

Figure 1. *Pellet of the correct shape and measurement of its length from the top of protrusion to the end with depression by the standard method*

The length measured by the standard method includes the pellet body, the spaces in the depression and around the protrusion that are not filled with fuel. The edges of the pellets at the end with depression are thin and uneven, they are easily destroyed by touch or pressure. Therefore, the result of measuring the length depends on subjective factors: the position of the pellet during measurement and the pressing force of the calliper jaws. In this regard, it is impossible to correctly determine the mass of fuel in the pellet from the length of the pellet measured by the standard method. In the standards [15; 16], it is accepted that pellets that remain on a sieve with round holes with a diameter of 3.15 mm have a length of more than 3.15 mm. This means that

for fragments of pellets and very short pellets that remain on the sieve and have a shape close to a thin disk, a length of 3.15 mm should be taken. With a considerable content of short pellets and debris, this can considerably affect the determination of the average length.

According to R.C. Akdeniz and O. Esmer pellets may break during production with the formation of bevelled and torn edges. Due to deviations in the technological process, pellets with cracks of different orientations can form at the output of the matrix, and the geometric shape may differ from the cylindrical one [21]. In [18], there are no instructions for measuring the length of irregular fragments and pellets, and therefore there is a need for a more objective but simple method for determining the length, which would be suitable for all pellets and their fragments.

L. Sikanen and T. Vilppo noted that pellets do not break on perfectly flat surfaces at an angle of 90° to the axis, so they measured the length between the midpoints on the fault surfaces [22]. When measuring manually, this approach causes subjective errors. To characterise the granular feed T. Winowiski proposed to weigh 10 grams of pellets, count their number and then calculate the average weight of one, but if the pellet does not have a full diameter, it is not considered [23]. With this approach, some pellets were subjectively excluded from the measurements. H. Gilvari et al. developed an image processing technique to determine the length of individual pellets – as the distance between two lines taken from the end points of the pellet shadow image perpendicular to its axis [24]. A long pellet on a horizontal screen gives a shadow, the size of which characterises its length with a certain approximation, and a short one lies like a flat disk and its shadow characterises its diameter rather than length.

Given the dependence of the combustion intensity on the shape and size of individual particles, the use of the average length for mathematical description of the combustion of a layer of polyfraction pellets is unacceptable. L. Sikanen et al. in the experimental study of combustion characterised the granulometric composition by a histogram of distribution over narrow ranges of pellet lengths (L, mm): $L<3$; $3<L<5$; $5<L<10$; $10<L<15$; $15<L<20$; $20<L<25$; $25<L<30$; $30<L$ [22]. R.C. Akdeniz and O. Esmer used unequal wide intervals: $L<3.15$; $3.15<L\leq20$; $20<L\leq35$; $35<L\leq38$; $38<L\leq40$; $40<L\leq45$; $45<L$ [21], and H. Gilvari et al. used even fewer wide intervals of $3.15<L<15$; $15<L<30$; $30<L$ [24]. In these studies, when constructing histograms, different widths of the pellet length intervals were taken without appropriate statistical substantiation.

The purpose of this study is to substantiate the method for determining the length of single pellets, which would be suitable for all pellets and their fragments of various shapes present in the studied portion, to determine statistical characteristics of the distribution of pellets by length.

MATERIALS AND METHODS

The study was conducted using experimental and analytical methods

Experimental part

Industrial-made wood and straw pellets with nominal diameters of 6 mm and 8 mm were used to test the proposed methods for achieving this purpose. For the obtained pellets, the moisture content [25] and ash content [26] were determined by standard methods.

Substantiation of the method for determining the length of individual pellets. 4 sets of wood and straw pellets with diameters of 6 mm and 8 mm were prepared. Each set contained 12 undamaged pellets of regular shape (with a protrusion at one end and a depression at the other), ranging in length from minimum to maximum. The length of all pellets in each set was determined by three alternative methods.

The first measurement of the length of each pellet along its axis from the top of the protrusion to the end with the depression L was performed by the standard method (Fig. 1) [18] using a digital calliper with a division value of 0.01 mm. The second time, the length of each pellet was measured as the distance along the axis of the pellet from the top of the protrusion to the bottom of the depression L_1 (Fig. 2), i.e., measured the length of the pellet at which it is filled with fuel.

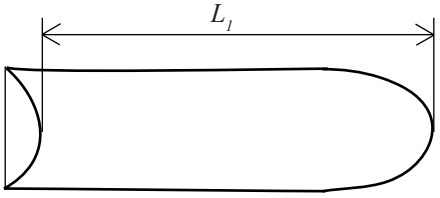

Figure 2. *Measuring the length of the pellet from the top of the protrusion to the bottom of the depression*

The third determination of the length is proposed to be conducted by an indirect method. Each pellet was weighed on a digital scale with a resolution of 0.01 g. The equivalent length Le of each pellet was calculated, that is, the length of a pellet in the form of a rectangular cylinder having a mass equal to the mass of a real pellet:

$$Le = \frac{4m}{(\rho\pi d^2)} \quad (1)$$

where: m – pellet weight, kg; d – average diameter of these pellets, m; ρ – average density of these pellets, kg/m^3.

The average diameter of pellets was determined by a method close to the standard [18]. Therewith, 20 pellets

of the correct geometric shape were selected for measurements, that is, without cracks and other defects, the diameter was measured with a calliper with a division value of 0.05 mm, and the resulting average diameter value was rounded to 0.1 mm.

The density of pellets was determined by the stereometric method [27], with the difference that only long pellets of regular cylindrical shape without visible cracks were selected for measurements. At least 10 rectangular cylinders with a length of at least 20 mm were cut out of the selected pellets and their ends were ground. The length and diameter of the obtained cylindrical pellet sections were measured with a calliper with a division value of 0.05 mm and weighed on an analytical scale with an accuracy of 0.001 g. Based on these data, the density of individual pellets and the average density of pellets of the test sample were calculated. The maximum error in determining the average pellet density is estimated at ±7 kg/m^3. Next, the results of determining the length obtained by different methods were compared, and as shown below, the main method was accepted the calculation and experimental determination of the equivalent length of all pellets and their fragments present in the studied portions of wood and straw pellets.

To analyse the length distribution of pellets, a sample weighing about 1 kg was taken, and then a shortened test portion weighing at least 0.1 kg was separated from it, focusing on the fact that it contained at least 200 pellets. The content of the fine fraction was determined by sieving with 3.15 mm diameter round holes in accordance with the standard method [17]. All pellets and their fragments remaining on the sieve were weighed individually, and their equivalent lengths were calculated using equation (1).

Analytical part

The experiments resulted in numerical series of the determined mass of each pellet m_i and the corresponding calculated equivalent lengths Le_i for all n pellets and fragments in the studied portions. The data of individual definitions of equivalent pellet lengths of each portion were converted into ordered rows: $Le_1 \le Le_2 \le \cdots \le Le_{n-1} \le Le_n$. For the studied pellet portions, the following were determined by their equivalent lengths: the largest and smallest length, the arithmetic mean length, the standard deviation of lengths, the median and mode of lengths, the probability and mass fraction of pellets with a length of less than 3 mm, the probability and mass fraction of pellets with a length of less than 10 mm.

To describe the distribution of pellets by length, the possibility of applying various methods of cluster analysis [28] was considered and the modal method [29] was chosen. The modal method, which is based on the analysis of the probability density distribution, was developed [30; 31] and is widely used in pattern recognition and artificial intelligence systems. Regarding the cluster analysis of the distribution of pellets by length, it was proposed to find distribution of the probability density over intervals of equivalent length and, considering the achievable error in its determination, the width of the intervals was assumed $\Delta=1$ mm or more. The n pellets were distributed at j equal intervals of equivalent lengths. For the first interval: $0<Le_{j=1}\le\Delta$, for the second: $\Delta<Le_{j=2}\le 2\Delta$ etc. to cover the longest pellets present in a sample.

For each of the j intervals the number of pellets having an equivalent length within the interval n_j, the arithmetic mean equivalent length of the pellets of the interval $Le_{j,av}$, and the frequency as an estimate of the probability P_j of pellets in the interval were determined:

$$P_j = \frac{n_j}{n} \tag{2}$$

Next, the probability density of falling pellet lengths was determined by j intervals:

$$F_j = \frac{P_j}{\Delta} \tag{3}$$

Based on the obtained data, a graph of points $F_j=f(Le_{j,av})$ was constructed and connected by a smoothed line, which approximately depicts the probability density distribution function of the random length of pellets in the studied portion and in their general set.

To identify ranges with higher probability density, an additional line of average probability density F_{av} was built for the entire portion of pellets:

$$F_{av} = \frac{1}{(j \cdot \Delta)} \tag{4}$$

Considering the constructed graphs $F_j=f(Le_{j,av})$, local probability thickenings were noted, and the maximums of probability density were identified. Values of equivalent length of pellets corresponding to local maxima of probability density were taken as the centres of attraction of clusters, and each of the pellets was assigned to the cluster with the nearest centre of attraction, the number of pellets n_k in each K of the detected clusters was determined.

For each of the K clusters, there were determined the probability (frequency) of pellets entering the cluster:

$$P_k = \frac{n_k}{n} \tag{5}$$

and the arithmetic average of the pellet length of a given cluster $Le_{k,av}$, and the mass fraction of pellets in the cluster:

$$M_k = \frac{P_k \cdot Le_{k,av}}{\sum_{k=1}^{k=K}\left(P_k \cdot Le_{k,av}\right)} \tag{6}$$

Based on the results of cluster analysis, cluster histograms were constructed – histograms of the probability distribution P_k and mass fraction of pellets M_k by clusters with the calculated average pellets length $Le_{k,av.}$

RESULTS AND DISCUSSION

Characteristics of pellets

Table 1 shows the main characteristics of pellets with diameters of 6 and 8 mm – "white" pellets made of pure pine wood with cyphers WP6 and WP8, straw (made of wheat straw) – with cyphers SP6 and SP8, which were used to test approaches to determining the length of pellets and statistical characteristics of their distribution by length.

Table 1. *Main characteristics of pellets*

Pellets	*DN*	*d*, mm	W_{ar}, %	A_d, %	ρ, kg/m^3	*FP*, w-%
WP6	*D*06	6.0	4.5	0.5	1185	1.30
WP8	*D*08	8.2	6.9	0.6	1141	0.56
SP6	*D*06	6.0	9.2	10.1	1273	0.88
SP8	*D*08	8.0	10.4	7.2	1215	0.25

Notes: *DN – pellets class by diameter; d – actual average pellet diameter; W_{ar} – a mass fraction of moisture; A_d – ash content on dry weight; ρ – average pellets density; FP – the content of fine particles less than 3.15 mm in size*

Results of choosing a method for determining the length of pellets

In Figure 3, for example, the results of determining the lengths of WP6 wood pellets of regular shape (with a protrusion and a depression) by three alternative methods are presented. For long pellets, the ratio $\frac{L}{L_1}$ was only 1.04, and for the shortest ones, it reached 1.6; which indicates a considerable influence of the depression size on the result of measuring the length of short pellets.

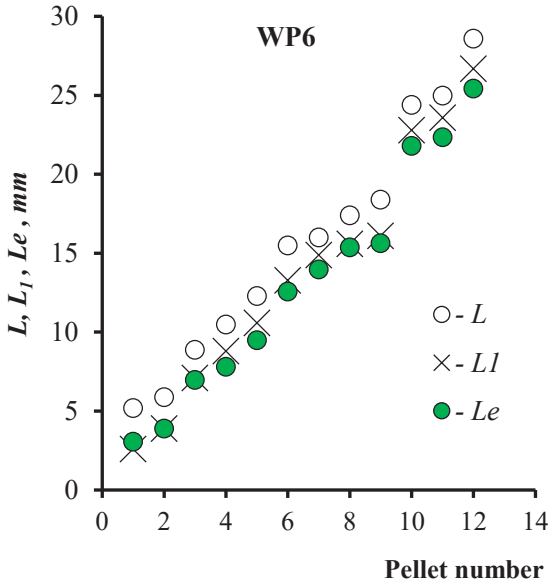

Figure 3. *Measured L, L_1 and calculated Le lengths of WP6 wood pellets*

Length measurement results L and L_1 differed: at a diameter of *D*06 by an average of 1.8 mm for wood and 2.0 mm for straw pellets; and at a diameter of *D*08 of 2.9 mm for wood and 2.0 mm for straw pellets. Smaller values L_1 can be considered as an offset of the measurement result by excluding the axial size of the depression. Length measurement results L_1 and calculated equivalent lengths Le differed much less: with a diameter of *D*06 for wood pellets by an average of 0.7 mm and for straw pellets by 0.6 mm; with a diameter of *D*08 for wood pellets by 0.3 mm and for straw pellets by 0.2 mm. The difference between L_1 and Lewas less than the maximum possible error in determining the equivalent length. For all pairs definition L_1 and *Le*, the correlation coefficient was R^2=(0.993… 0.999).

It can be concluded that for pellets of the correct shape (with a protrusion and a depression), the calculated equivalent length *Le* and the length, measured along the axis from the top of the protrusion to the bottom of the depression L_1 coincided or were close. This gives grounds to replace the direct measurements of the

length of the pellets L_1 (from the top of the protrusion to the bottom of the depression) with weighing the pellets, followed by the calculation of the equivalent length *Le* depending on (1). For irregularly shaped pellets and fragments, only the equivalent length can be determined *Le*. In this regard, the calculation of the equivalent length via-weighing is proposed to be applied to all pellets and their fragments.

Characteristics of the granulometric composition of pellets

Table 2 shows the general characteristics of the granulometric composition of the studied pellets, which are obtained based on the results of calculation and experimental determination of equivalent lengths *Le* of all pellets and their fragments. Analysis of the dependence (1), considering the measurement errors of the values included in it, showed that for pellets with diameters of 6 mm and 8 mm weighing about 0.1 g, the maximum error in determining the equivalent length was up to 0.2 mm, and for pellets with a mass of 0.7 g up to 0.7 mm. In statistics, it is accepted that to analyse measurement results, their errors should not exceed 1/5 of the standard deviation of the results obtained. The described method was tested for pellets characterised by a standard deviation of equivalent length *STD Le* in the range from 3.9 mm to 6.2 mm (Table 2). The error in determining the equivalent pellet lengths in the described study met the requirements of the following statistical analysis of the distribution of pellets by length.

From Table 2 it can be seen that even after sieving with holes of 3.15 mm, there were short particles with an equivalent length of less than 1 mm in the superlattice part of the pellets. According to the standards [15; 16], their length would need to be taken as 3.15 mm, but this would lead to a considerable overestimation of the pellet lengths.

Table 2. *General characteristics of the granulometric composition of the studied pellets*

Pellets	Le_{min}, mm	Le_{max}, mm	Le_{av}, mm	STDLe, mm	Mn, mm	Md, mm	PNL3, %	PWL3, w-%	PNL10, %	PWL10, w-%
WP6	0.9	30.7	10.1	6.2	8.4	5.4	9	2	56	31
WP8	0.8	24.0	6.6	4.8	5.6	0.8	28	7	80	56
SP6	0.3	24.2	6.4	3.9	4.5	4.4	15	4	83	65
SP8	0.3	24.1	4.2	4.0	3.1	0.3	49	14	91	70

Notes: *Le_{min} – length of the shortest pellet; Le_{max} – length of the longest pellet; Le_{av} – arithmetic average length of pellets; STD – standard deviation; Mn – median pellets length; Md – pellets length mode; PNL3 – pellets fraction Le<3 mm; PNL10 – pellets fraction Le<10 mm; PWL3 – mass fraction of pellets Le<3 mm; PWL10 – mass fraction of pellets Le<10 mm*

In portions of pellets with a diameter of 6 mm, the content of particles with an equivalent length of less than 3 mm ranged from 9% to 15% in terms of their number, and in pellets with a diameter of 8 mm, their content was considerably higher – from 28% to 49%. The increased content of particles with an equivalent length of up to 3 mm was more typical for straw pellets. By weight, pellets with an equivalent length of less than 3 mm were (2 ... 7) w-% in wood pellets, and their content in straw pellets SP8 reached 14 w-%.

In the studied pellets with a diameter of 6 mm, the content of particles with a length of less than 10 mm ranged from 56% to 83%, in pellets with a diameter of 8 mm, there were more of them – from 69% to 91%. The increased content of particles with an equivalent length of less than 10 mm in both quantity and mass fractions was more typical for straw pellets and reached 65 w-% for 6 mm pellets and 70 w-% for 8 mm pellets. For all the pellets studied, the mean, median, and mode of equivalent length differed in value, which indicates a deviation in the distribution of their lengths from normal, which is more noticeable for pellets with a diameter of 8 mm. The average equivalent length Le_{av} of wood pellets was larger than that of straw pellets.

Distribution of the probability density of pellets by lengths

Figure 4 shows the obtained graphs of the probability density distribution of pellets by lengths $F_j=f(Le_{j,av})$ and average equivalent pellet lengths $Le_{j,av}$ at length intervals Δ=1 mm; the graphs show several local maxima. The difference between the equivalent lengths of pellets corresponding to adjacent local probability maxima was (2 ... 4) mm. This may indicate that during the production and transportation of pellets, breakage does not occur in arbitrary places along the length, but in certain places, possibly along the boundaries of the layers of compressed biomass particles formed in one pass of the pressure rollers on the press matrix.

A probability density greater than the average was observed in the following ranges of equivalent lengths: for WP6 wood pellets at *Le*=(1.5 ... 16) mm, WP8 at *Le*= =(0.8 ... 10.5) mm, for SP6 straw pellets at *Le*=(0.3 ... 10.5) mm, SP8 at *Le* = =(0.3 ... 7.5) mm. To summarise, for straw pellets, the probability density above the average was shifted to the zone of shorter pellets compared to wood pellets. Wood and straw pellets with a diameter of 8 mm are characterised by an increased probability shifting to the zone of shorter pellets compared to pellets with a diameter of 6 mm.

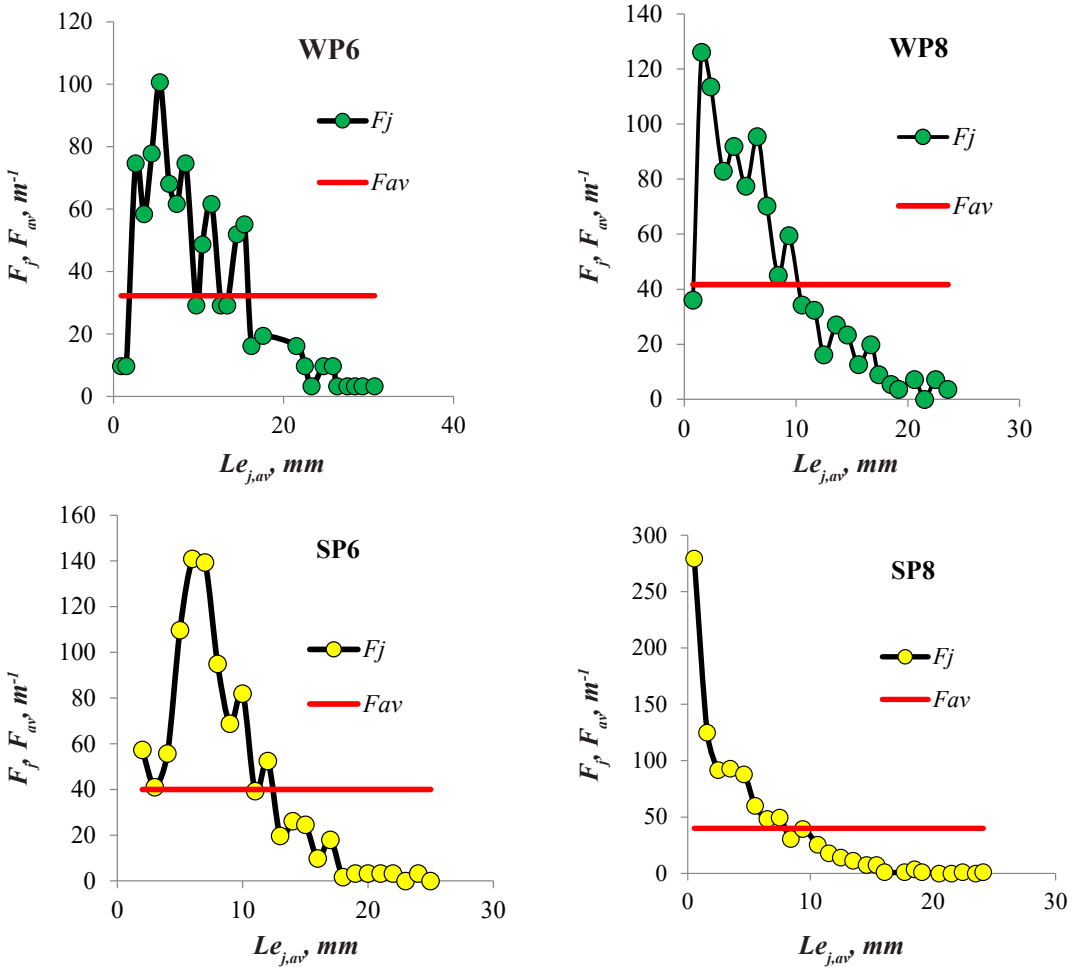

Figure 4. *Probability density F_j and the average equivalent length $Le_{j,av}$ of wood WP6, WP8 and straw SP6, SP8 pellets at intervals Δ=1 mm*

Figure 5, for example, shows graphs of the probability density distribution for WP6 wood pellets with increasing interval widths Δ from 2 to 15 mm. From the comparison of the data shown in Figure 4 and 5, it follows that as the interval width increased, the number of local maxima of probability density decreased: if at Δ=1 mm 8 local maxima were observed, then at Δ=2 mm there were 4 local maxima, and only one global maximum was shown on the graph for Δ=3 mm or more. As the width of the intervals Δ increased, the information about the content of pellets of short length and about the presence of local maxima of probability density was lost. In this regard, to apply the modal method of cluster analysis, it is necessary to determine the distribution of the probability density of pellets over lengths with an interval width of no more than 2 mm.

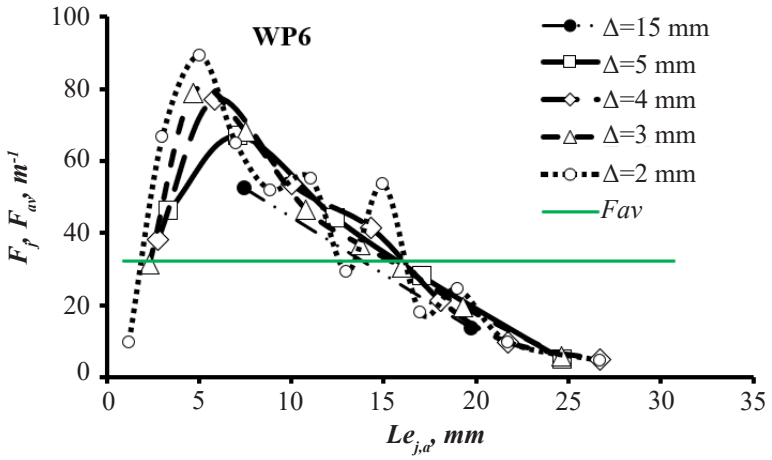

Figure 5. *Probability density distribution F_j of WP6 pellets at length intervals from Δ=2 mm to Δ=15 mm*

Distribution of pellets by clusters of their lengths

For each type of pellet according to the data in Figure 4, the presence of K=8 local probability density maxima were detected. For other pellets not described in this paper, 6 to 10 local probability density maxima were found. Figure 6 shows cluster histograms of the probability distribution P_k and the mass fraction of pellets M_k for K clusters with an average pellets length $Le_{k,av}$.

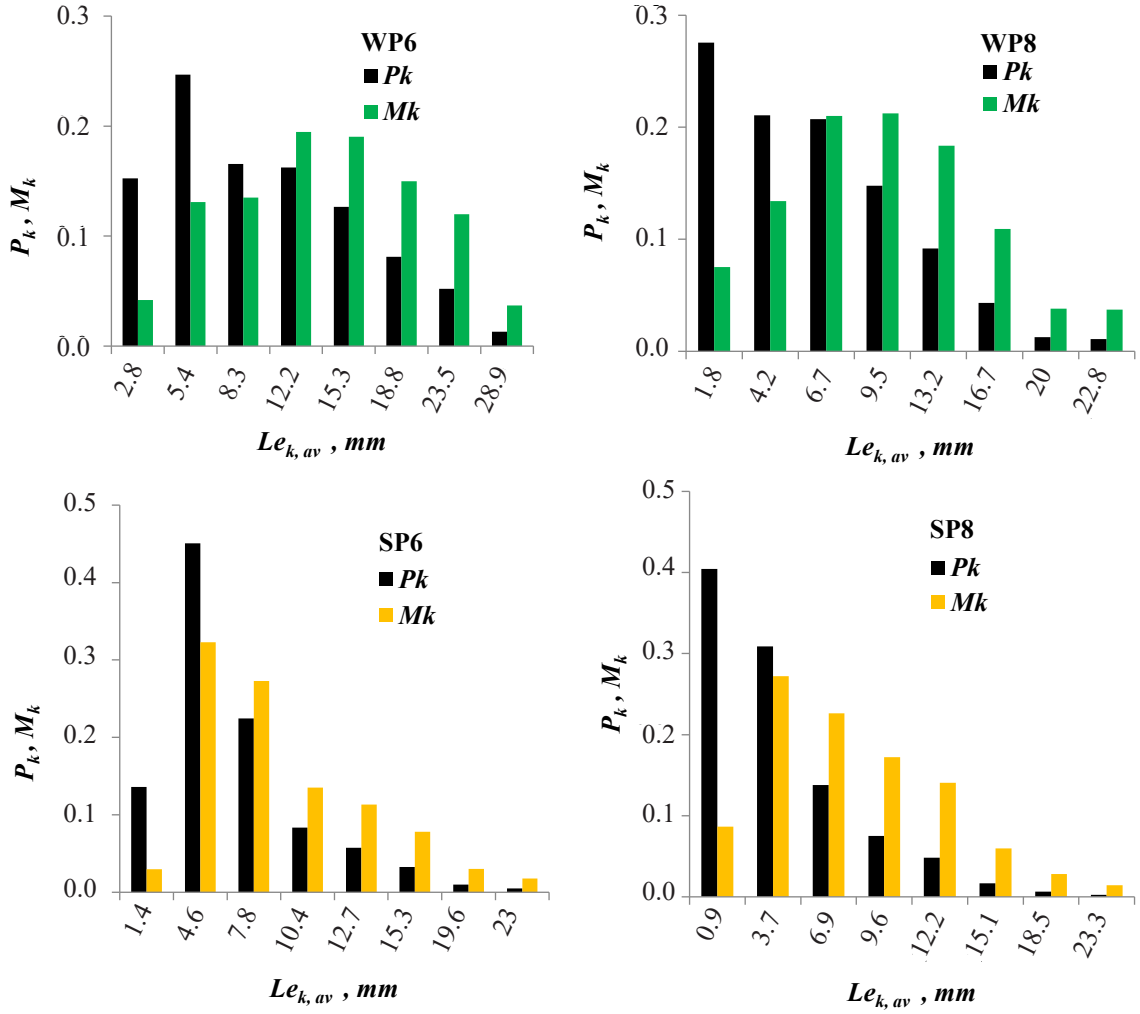

***Figure 6**. Probability distribution P_k, fractions by weight M_k and average length $Le_{k,av}$ of wood WP6, WP8 and straw SP6, SP8 pellets by clusters of lengths*

A common feature of wood and straw pellets with a diameter of 6 mm was the presence of clusters of short pellets with an average length of 2.8 mm and 1.4 mm with a probability (0.10...0.15), and for pellets with a diameter of 8 mm, the presence of clusters with an even smaller average length of pellets of 1.8 mm and 0.9 mm with a more considerable probability (0.28 ... 0.40). The detection of clusters with such short pellets was made possible by the experimentally – calculating determination of equivalent lengths for all particles in pellets, which was impossible when determining the pellet lengths using the standard method.

WP6 wood pellets had the highest mass content in clusters with an average length of 12.2 mm and 15.3 mm, and WP8 – in clusters with considerably shorter pellets of 6.7 mm and 9.5 mm. SP6 straw pellets had the highest mass content in clusters with an average length of 4.6 mm and 7.8 mm, and SP8 – in clusters with even shorter pellets of 3.7 mm and 6.9 mm.

CONCLUSIONS

The possibility of determining the equivalent length of pellets by an indirect experimental calculation method based on their individual weighing, identification of the average diameter and average density characteristic of the studied portion of pellets is substantiated. The method of indirect determination of the equivalent length of pellets is suitable for determining the length of all pellets, including irregular pellets and fragments. Replacing direct length measurement with pellet weighing reduces the impact of subjective factors.

The granulometric composition of pellets is proposed to be characterised by cluster histograms that reflect the distribution of probability, mass fraction, and average

equivalent length across clusters. Cluster analysis is proposed to be conducted using the modal method, grouping pellets around objectively existing centres with an increased probability density, which can be identified on graphs of the probability density distribution at intervals of pellet lengths of no more than 2 mm. In the future, using the proposed approaches to determining the length of single pellets and cluster analysis of the distribution of pellets by length, the research can proceed to the formulation of a mathematical description of the burnout of polyfraction pellets. It is advisable to apply the proposed approaches to improve the standard for determining the length of pellets.

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Визначення довжини одиночних пелет та розподілу пелет за довжинами

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Анотація. Форма та розмір часток палива впливають на інтенсивність їх горіння та математичний опис процесу. Відомі методи не дозволяють коректно виміряти довжини всіх пелет в пробі та описати їх гранулометричний склад. Метою роботи було обґрунтування методу визначення довжини одиночних пелет і визначення статичних характеристик розподілу пелет за довжинами. Поставлена мета досягнута застосуванням запропонованого методу непрямого визначення довжини кожної пелети шляхом її зважування з наступним розрахунком еквівалентної довжини та модальним кластерним аналізом розподілу пелет за довжинами, що базується на розподілі густини ймовірності. Найбільш важливі результати полягають в тому, що експериментально-розрахункове визначення еквівалентної довжини дає результати, що збігаються з прямими вимірюваннями стосовно пелет правильної форми, але на відміну від прямих вимірювань також може застосовуватися для визначення еквівалентних довжин пелет неправильної форми та їх уламків. Кластеризація дозволила групувати пелети довкола об'єктивно існуючих локальних максимумів на розподілі густини ймовірності, які можна ідентифікувати при інтервалах довжин пелет не більше 2 мм. Значимість отриманих результатів полягає в тому, що непрямий метод визначення довжин пелет дозволяє замінити вимірювання довжин пелет їх зважуванням, що виключає суб'єктивні фактори при вимірюваннях довжин пелет неправильної форми та їх уламків. Кластеризація дозволила охарактеризувати гранулометричний склад пелет гістограмами розподілу ймовірності, масової частки та середньої довжини за кластерами. Із застосуванням запропонованих підходів визначено гранулометричний склад промислово вироблених деревних і солом'яних пелет та встановлено, що для пелет діаметром 8 мм характерна підвищена ймовірність у кластерах з меншими довжинами у порівнянні з пелетами діаметром 6 мм, для солом'яних пелет характерна вища ймовірність в кластерах з меншими довжинами у порівнянні з деревними пелетами

Ключові слова: пелети, вимірювання довжини, визначення довжини, розподіл густини ймовірності, кластерний аналіз, гістограма, гранулометричний склад

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Weather Factors and Their Influence on the Adaptive Properties of Winter Wheat Varieties in the Western Forest-Steppe of Ukraine

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Abstract. The yield potential of winter wheat (*Triticum aestivum* L.) is formed in changing weather conditions and depends on the proposed agro-technological measures, to which the response of a particular variety is different. The purpose of this study was to determine the influence of weather factors on the field germination of soft winter wheat seeds, the growth and development of plants in the autumn and wintering in the zone of the Western Forest-Steppe of Ukraine, by sowing high-quality basic seed, careful soil preparation and the presence of optimum environmental factors. A sufficient level of productive soil moisture, which protects young shoots from possible deficiency after germination and is a long-term source of moisture at the next stages of organogenesis, has a great influence on obtaining friendly and timely shoots. Often overwintering conditions, when plants suffer from low negative temperatures at the beginning and at the end of the winter period, ground ice crust, resumption of vegetation in winter are the causes of freezing, loss, and ultimately a decrease in yield and seed quality. It has been confirmed that an increase in the temperature regime in 244-247°C in the autumn-winter period and the optimal amount of precipitation contribute to sufficient (31.6-34.6 mm) productive soil moisture (0-20 cm), which positively influences the process of germination of soft winter wheat, provides a high percentage of field germination of seeds of varieties (93.8-94.5%), lengthens the autumn development of plants by 3-12 days, which causes 3.5-5.7% higher accumulation of sugar content in the tillering nodes and a high percentage of overwintering (up to 95.5-96.4%). Varieties of the forest-steppe ecological type of soft winter wheat have insignificant phenotypic variability of adaptive traits, therefore, in the production of grain and seed products, it is recommended to give preference to the plant varieties listed in the Register, suitable for distribution in Ukraine for the Forest-Steppe zone, Polissya. The recommendations set out in this scientific work will help agricultural producers of the studied soil and climatic zone to carry out an effective, more ecologically plastic, highly productive variety replacement

Keywords: air temperature, precipitation, soft winter wheat, field germination of seeds, autumn development of plants, overwintering

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INTRODUCTION

The yield potential combines the importance of the biological properties of plants in the formation of the possible maximum yield due to the variability of weather conditions and their adjustment by organizational and technological measures. The introduction into agricultural production of ecologically plastic varieties with different rhythms of development contributes to an increase in the yield of grain crops and stabilization of the production of grain and seeds [1-6].

According to some authors, V.P. Dmitrenko was the first to work on the concept, meaning, and content of the climatic potential of yield (potential, actual) as a prognostic and calculated indicator when calculating the yield of winter wheat. The growing season of soft winter wheat covers almost the entire calendar year, which makes it possible to determine the influence of weather factors on the growth and development of plants, the state of dormancy, and ultimately on the productivity of plants [7; 8].

Agrometeorological resources, which are determined by such environmental factors as heat, moisture and air, and nutrient minerals in production conditions for the formation of sustainable yields of winter wheat are used no more than 60%, therefore, considering the climate change in Ukraine, it is necessary to introduce varieties adapted to the ecological regions which are significantly influenced by unfavorable biotic and abiotic factors [9; 10].

One of the most important indicators of biological control in the technology of growing any crop is the field germination of seeds [11]. The period from sowing to germination is critical, since the seedling doesn't have nutritional organs. Therefore, it is very sensitive to all kinds of factors, and metabolic processes are provided by those resources that are accumulated by the seeds due to the productivity of the mother plant. The lower the field germination of seeds, the less evenly the placement of the plant on the area is, as a result of which the differentiation of individual development, overwintering and the state of crops as a whole will increase [12].

Research results show that under production conditions, due to sowing high-quality base seeds, careful soil preparation and the presence of optimum environmental factors, high field germination rates are provided, but reaching the level of 95-98% is a difficult task [13; 14].

A sufficient level of productive soil moisture, which protects young shoots from possible deficiency after germination and is a long-term source of moisture at the next stages of organogenesis, has a great influence on obtaining friendly and timely shoots [15].

Often wintering conditions are the causes of freezing, loss, and ultimately a decrease in yield and seed quality [16; 17]. It is because plants suffer from low temperatures, ground ice crust, resumption of vegetation at the beginning and at the end of the winter period.

Scientists around the world are unanimous that the variety plays a large positive role in increasing the adaptive properties of crops, but the percentage of its influence is different, therefore, the need for adaptation of winter wheat varieties to stress factors associated with global climate change is of strategic importance. Breeding must respond to this challenge of nature by creating frost and winter-hardy varieties with a high potential for productivity and product quality [18; 19].

The purpose of this study was to identify the influence of weather factors on the field germination of soft winter wheat seeds, the growth, and development of plants in the autumn period and wintering in the zone of the Western Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The object of research was the varieties of soft winter wheat from various originator institutions, included in the Register of plants varieties suitable for distribution in Ukraine – Trudivnytsa myronivska, MIP Vyshyvanka, Gratsia belotserkivska, Kvitka poliv, Vodograi belotserkivskiy, Spivanka poleska. Field experiments in the crop rotation were carried out in the laboratory of the Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences, during 2018-2021. The total area of the experimental site was 60 m^2, the accounting area was 50 m^2. Placement of variants – systematic, repetition – threefold.

The soil of the research plots was gray forest, superficially gleyed, light loamy, which was characterized by the following indicators: humus content (according to the Tyurins) – 1.7%, the amount of absorbed bases – 13.7 mg-eq per 100 g of soil, puddle-hydrolyzed nitrogen (according to Cornfield) – 89.6 mg/kg, mobile phosphorus and exchangeable potassium (according to the Kirsanovs) – 69.5 and 68.0 mg/kg, respectively. As for gradation, such a soil has a very low nitrogen supply, medium phosphorus supply, and low potassium supply. The reaction of the soil solution (pH sol – 5.4) is weakly acidic.

Agricultural technology for growing varieties of winter wheat is common for the crop in this area. The predecessor is winter rapeseed. Sowing time – 09.25-01.10. Seeding rate – 5.5 million viable seeds/ha, application of mineral fertilizers (basic) – $N_{30}P_{70}K_{120}S_{21}$. Seed treatment – dressing agent Vitavax 200FF, 34% (water suspension concentrate, 3.0 l/t). Plant protection against weeds and diseases – herbicides: roundup, 48% (4.0 l/ha); Granstar, 75% (water-soluble granules, 0.025 g/ha); fungicide: Falcon (emulsion concentrate, 0.6 l/ha).

According to the Lviv hydrogeological reclamation station, the sum of the temperature regime and the amount of precipitation in the autumn and winter periods and the duration of the autumn vegetation and dormancy of plants were determined. Using the method

of counting sites, the dates were established, based on calculations: the beginning of seedlings (at least 15% of seedlings appeared), mass seedlings (at least 50%), full seedlings – 75% or more, the end of the phase – the appearance of the last seedlings and the field germination as the ratio of the number of seedlings to the total number of sown germinating seeds [20; 21].

Using the method [22], phenological observations of the growth and development of plants in the autumn were carried out. Linear measurements such as the height of plants and the length of the root system, and quantitative measurements such as the presence of shoots and leaves on the plant were taken into account. The total content of mono- and disugars was determined with the method of photometry using picric acid [23]. With a weighed portion of the samples pounded in a mortar and dried in a drying oven (105°C each), the sugars were extracted with water in a water bath (10 min. 100°C). The concentration of total sugars after acid hydrolysis (3.3% HCl) was determined colorimetrically at 490 nm using a calibration curve constructed using a scale of standard solutions of glucose or hydrolyzed sucrose. The dry matter content in the plant material was calculated by the gravimetric method.

The wintering of plants of varieties was carried out based on the data from autumn and spring records of the state of crops in each repetition concerning to plants that restored spring vegetation to field germination of seeds [24]. The range of variability (R) of cultivar traits and weather conditions was determined by the difference between the maximum and minimum values. The statistical reliability of the experimental data, variance, and correlation between the sugar content in the tillering nodes of soft winter wheat varieties and the duration of the autumn growing season and overwintering were established [25] using programs Microsoft Excel and "Statistica 6.0".

RESULTS AND DISCUSSION

Over the years of our research, the weather conditions were contrasting, which made it possible to give an objective assessment of their effect on the field germination of seeds of soft winter wheat (Table 1).

***Table 1**. Field germination of soft winter wheat seeds depending on the productive soil moisture (average for varieties, 2018-2020), %*

Year	Indicators of the sowing-germination period						Field germination of seeds	
	Air temperature		Precipitation amount		Productive soil moisture*			
Average long-term indicator	%	±	mm	±	mm	±	%	±
	11.2	–	19.0	–	34.6	–	94.5	–
2018	10.7	-0.5	21.6	2.6	31.6	-3.0	92.4	-2.1
2019	12.3	1.1	32.8	13.8	33.8	0.8	93.8	0.7
2020	14.4	2.2	72.1	53.1	38.4	3.8	97.2	2.7

***Note**: *Productive soil moisture up to 20 mm – sufficient, 20-40 mm – satisfactory*

In 2018, during the sowing period, germination was characterized by 0.5°C lower air temperature and 2.6 mm higher precipitation compared to the long-term average. Under such conditions and according to the predecessor of winter rapeseed, the productive soil moisture was 31.6 mm. The highest temperature regimes by 1.1 and 2.2°C and a large amount of precipitation by 13.8 and 53.8 mm were recorded in 2019 and 2020. That provided the productive soil moisture at the level of 33.8 and 38.4 mm. With sufficient moisture supply, the field germination rate was higher than the previous year by 0.7-2.7%, that is, the weather conditions contributed to the intensive germination of seeds and the receipt of friendly seedlings.

In close connection with controlled and uncontrolled environmental factors, the structure of plants and the entire crop as a whole was formed in the autumn. The termination of the autumn vegetation of plants in 2018 occurred at the beginning of the third decade of November, which corresponds to the average long-term periods, therefore the sum of active temperatures was 567°C (Table 2). The growing season of winter wheat plants between 2019 and 2020 was longer (before the beginning of December) and warmer, which is due to the sums – 664 and 614°C. Over the years of research, in comparison with the long-term average sum of temperatures of 320°C, the increase was 247-344°C, which confirms a significantly warmer temperature regime and a longer autumn period of growth and development of plants of varieties – 56-65 days. During this period, the plants accumulated the optimal sugar content in the tillering nodes (28.5-30.7%).

***Table 2**. Influence of the autumn temperature regime and the age of soft winter wheat plants on the carbohydrate content in the tillering nodes (2018-2020), %*

Year	The sum of temperatures, °C for the autumn period				Average long-term data, °C	Duration of autumn vegetation of plants, days	Sugar content in tillering nodes,%
	September	October	November	Sum			
2018	107	335	125	567	320	56	28.5
2019	123	326	195	664		65	32.3
2020	144	344	126	614		64	30.7
The average	112	248	72	432		62	30.5

An increase in the content of water-soluble carbohydrates in cells is one of the adaptive responses of plants to the effects of cold. The importance of sugars as the main protective substances in the development of frost resistance of winter wheat is undoubted, since they play an important role in ensuring the structural and functional stability of cells in conditions of loss of water. Characterizing the accumulation of sugars in the tillering nodes of plants, we did not establish significant differences between the varieties, they were within the error (SSD_{05}=0.9, 0.7, 0.6%) (Table 3). However, the range of variation over the years revealed a significant 2.4% (variety Trudivnytsa myronivska) – 4.3% (Gratsia belotserkivska).

***Table 3**. Correlation (r) between the sugar content in the tillering nodes of soft winter wheat varieties and the duration of the autumn growing season (2018-2020)*

Variety	Sugar content in tillering nodes by year, %				R (range of variability)
	2018	2019	2020	The average	
Trudivnytsa myronivska	28.6	32.3	31.0	30.6	2.4
MIP Vyshyvanka	29.0	32.4	30.5	30.6	3.4
Gratsia belotserkivska	28.3	32.6	30.7	30.5	4.3
Kvitka poliv	28.7	32.2	30.4	30.4	3.5
Vodograi belotserkivskiy	28.2	32.3	30.5	30.3	4.1
Spivanka poleska	28.1	32.0	31.1	30.4	3.9
The average	28.5	32.3	30.7	30.5	3.8
SSD_{05}	0.9	0.7	0.6	–	–
Duration of the autumn growing season, days	56	65	64	62	–
Correlation (r)*	0.32	0.27	0.37	0.15	–

***Note**: *From 0 to 0.33 – weak, 0.33 to 0.66 – medium, 0.66 to 1.00 – strong, 1.00 – complete, both for direct (+) and inverse (–) correlation (r)*

At the time of the termination of the autumn growing season, the length of the root system of plants varied from 9.2 cm (cultivar Trudivnytsa myronivska) to 9.7 cm (cultivar Spivanka poleska), and the number of nodal roots was in the range of 3.0-3.4 pcs./plant (Table 4). The difference in plant height (0.1-0.6 cm), the number of shoots and leaves on the plant was unreliable.

***Table 4**. The development of soft winter wheat plants at the time of the termination of the autumn growing season, depending on varietal characteristics (2018-2020)*

Variety	Root system length		Plant height		Nodal roots		Quantity per plant of leaf		Shoots	
	cm	± to control	cm	± to control	pc	± to control	pc	± to control	pc	± to control
Trudivnytsa myronivska	9.2	–	16.1	–	3.0	–	2.5	–	6.5	–
MIP Vyshyvanka	9.6	0.4	16.7	0.6	3.3	0.3	2.8	0.3	6.8	0.3
Gratsia belotserkivska	9.0	-0.2	16.0	-0.1	3.1	0.1	2.5	0.0	6.3	0.2
Kvitka poliv	9.3	0.1	16.4	0.3	3.2	0.2	2.6	0.1	6.4	-0.1
Vodograi belotserkivskiy	9.4	0.2	16.7	0.6	3.3	0.3	2.5	0.0	6.5	0.0
Spivanka poleska	9.7	0.5	16.5	0.4	3.4	0.4	2.8	0.3	6.7	0.2
The average	9.4	–	16.4	–	3.2	–	2.6	–	6.5	–
SSD_{05}	0.8		1.0		0.5		0.4		0.3	

Winter periods have been distinguished by a significant diversity in the last few years (Table 5). According to the average long-term sum of temperatures minus 308°C, in 2018-2019 this indicator was minus 84.4°C, in 2019-2020 – minus 36.4°C, and 2019-2020 – plus 135.0°C. The amount of precipitation in the winter period prevailed on an average long-term indicator by 17 mm (2018-2019), 11.7 mm (2019-2020) and 147.1 mm (2020-2021). The length of a day with temperatures below 0°C varied from 30 – in December to 61 – in January, the average being 46 days.

***Table 5**. Hydrothermal factors of the winter dormancy period of soft winter wheat plants (2018-2021)*

Month	Hydrothermal factor								
	Sum of temperatures, °C				Number of precipitation, mm				Duration of the winter period with temperatures below 0°C, days
	2018-2019	2019-2020	2020-2021	Mean annual data	2018-2019	2019-2020	2020-2021	Mean annual data	
December	54.0	12.0	81.0	-54.0	49.9	69.3	49.9	48.0	30
January	-12.4	-102.4	-21.7	-143.0	28.4	61.0	28.4	40.0	61
February	-126.0	54.0	75.0	-111.0	69.7	12.4	69.7	43.0	47
The sum of temperatures for the winter period	-84.4	-36.4	135.0	-308.0	148.0	142.7	147.1	131.0	46

***Table 6**. Overwintering of winter wheat plants, soft depending on the biological characteristics of the variety (2018-2021)*

Variety	Overwintering plants by years, %				R_1 (range of variability by varieties)
	2018-2019	2019-2020	2020-2021	Average	
Trudivnytsa myronivska	97.3	94.2	96.4	96.0	3.1
MIP Vyshyvanka	97.9	94.5	96.5	96.3	3.1
Gratsia belotserkivska	97.1	94.0	95.9	95.7	3.1
Kvitka poliv	98.0	94.3	96.6	96.3	3.7
Vodograi belotserkivskiy	97.0	94.0	95.6	95.5	3.0
Spivanka poleska	97.7	94.8	96.8	96.4	2.9
The average	97.5	94.3	96.3	96.0	3.2
SSD_{05}	0.5	0.6	0.9		
R_2 (range of variability over the years)	0.9	0.8	1.2	0.9	–
The sum of temperatures for the winter period	-84.4	-36.4	135.0	-308.0	–
Correlation (r)*	0.14	-0.72	0.40	–	–

***Note**: *From 0 to 0.33 – weak, 0.33 to 0.66 – medium, 0.66 to 1.00 – strong, 1.00 – complete, both for direct (+) and inverse (–) correlation (r)*

The cultivation of varieties of the forest-steppe ecological type of soft winter wheat confirmed their high adaptability to various changes in external factors in winter, provided by both modification and genotypic variability, which cannot be considered separately (Table 6). The range of variability of plant overwintering by cultivars (R_1) was unreliable and varied from 2.9% cultivar Spivanka poleska to 3.7% cultivar Kvitka poliv (SSD_{05}=0.5-0.9%) and reliable over the years (R_2) – 0.9-1.2% (SSD_{05}=0.9-1.2%). A strong inverse correlation was observed between the sum of temperatures (°C) in winter and overwintering of plants (%) in 2019-2020 (r= -0.72), the average straight line – in 2020-2021 (r=0.40) and a weak straight line – in 2018-2019 (r=0.14).

CONCLUSIONS

It has been established that when growing soft winter wheat in the Western Forest-steppe zone of Ukraine, the most limiting factors in the technological process are weather factors and variety. The adaptive ability has been confirmed, which has a deeply specific character and is closely related to the weather conditions of the place where the variety was created. Varieties of forest-steppe ecological type provide insignificant phenotypic

variability of adaptive traits, so the production is not recommended to give preference to varieties that are not in the Register of plant varieties suitable for distribution in Ukraine.

Changes in weather factors, in particular, an increase in the temperature regime by 244-247°C in the autumn-winter period and the optimal amount of precipitation, contribute to sufficient (31.6-34.6 mm) productive soil moisture (0-20 cm), providing a high percentage of field germination of seeds of varieties (93.8-94.5%). In 2018-2021 the duration of the autumn vegetation of plants was 3-12 days longer, which caused 3.5-5.7% higher accumulation of sugars in the tillering nodes, increasing the overwintering of plants to 95.5-96.4%.

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Погодні фактори та їхній вплив на адаптивні властивості сортів пшениці озимої в умовах Західного Лісостепу України

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Анотація. Потенціал урожайності пшениці м'якої озимої (*Triticum aestivum* L.) формується в мінливих погодних умовах і залежить від запропонованих агротехнологічних заходів на які реакція конкретного сорту різна. Метою цього дослідження було визначити вплив погодних факторів на польову схожість насіння пшениці озимої м'якої, ріст і розвиток рослин в осінній період та перезимівлю в зоні Західного Лісостепу України, за рахунок висіву якісного базового насіння, ретельної підготовки ґрунту та наявності оптимуму екологічних факторів. На отримання дружних і своєчасних сходів має великий вплив достатній рівень продуктивної вологості ґрунту, який захищає молоді пагінці від ймовірного дефіциту після з'явлення сходів і є тривалим джерелом зволоження на наступних етапах органогенезу. Часто умови зимівлі, коли рослини страждають від дії низьких негативних температур на початку і в кінці зимового періоду, притертої крижаної кірки, відновлення вегетації в зимовий період є причинами вимерзання, випадання, а в кінцевому результаті зниження урожайності й якості насіння. Підтверджено, що підвищення температурного режиму на 244–247 °С в осінньо-зимовий період та оптимальна кількість опадів, сприяють достатній (31,6–34,6 мм) продуктивній вологості шару ґрунту (0–20 см), що позитивно впливає на процес проростання пшениці озимої м'якої, забезпечуючи високий відсоток польової схожості насіння сортів (93,8–94,5 %), подовжує осінній розвиток рослин на 3–12 діб, що обумовлює більше на 3,5–5,7 % накопичення цукрів у вузлах кущіння та високий відсоток перезимівлі (до 95,5–96,4 %). Сорти лісостепового екологічного типу пшениці м'якої озимої мають незначну фенотипову мінливість адаптивних ознак, тому при виробництві зернової і насіннєвої продукції рекомендується віддавати перевагу внесеним до Реєстру сортам рослин, придатним для поширення в Україні для зони Лісостепу, Полісся. Викладені в цій науковій роботі рекомендації допоможуть сільськогосподарським товаровиробникам досліджуваної ґрунтово-кліматичної зони здійснювати ефективну, більш екологічно пластичну, високопродуктивну сортозміну

Ключові слова: температура повітря, кількість опадів, пшениця озима м'яка, польова схожість насіння, осінній розвиток рослин, перезимівля

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Forest Typology and Settlement Characteristics of the Emerald Network "The Lower Part of the Uda River Valley" in the Kharkiv Region

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Abstract. The importance and significance of the conservation of the Emerald Object "The lower part of the Uda River Valley" (UA0000295) in botanical and general ecological aspects is discussed in detail. It is located on the outskirts of Kharkiv with an area of 13,381.0 ha. The studied area combines floodplains of regions occupied by meadows, shrub fragments and forest vegetation, and pine forests with artificial pine plantations. Areas of the loess plateau with arable land and deciduous forests, as well. List of the leading plant species, area's, main ecological and biotic features of identified habitats under Resolution 4 of the Berne Convention, in particular, C1.222, C1.32, C1.33, C3.34, D5.2, E1.2, E2.2, E3.4, F9.1, F3.247, G1.11, G1.21, G1.41, G1.8, G3.4232, G1.A4, G1.A1 for the Emerald Object are presented. The largest areas are occupied by biotops of lowland bogs with sedge and reed thickets without stagnant water (D5.2). There are plain hay fields (E2.2) and wet and moist meadows with a predominance of grasslands (E3.4) and deciduous forests in medium rich and rich soils (G1.A1), fresh and dry forests, and Sarmatian-type forests (G3.4232). The typological diversity of the forest of the territory, the area covered with forest vegetation is 11,585.0 ha, were outlined. Oak (*Quercus robur* L.) (8,091.5 ha, 69.83%) with a predominance in its plantations of fresh maple-linden oak and Scots pine (*Pinus sylvestris* L.) (2,529.8 ha, 21.84%) with a predominance of fresh oak-pine sedge are the main forest-forming species. Some species have appropriate conservation status in Ukraine (*Botrychium lunaria* (L.) SW., *Dactylorhiza incarnata* (L.) Soo s.l., *Epipactis palustris* (L.) Crantz, *Anacamptis coriophora* (L.) R.M. Bateman, Pridgeon & M.W. Chase (*Orchis coriophora* L.), *A. palustris* (Jacq.) R.M. Bateman, Pridgeon & M.W. Chase (*Orchis palustris* Jacq.), and several species are protected at the regional level (*Centaurium erythraea* Rafn., *C. pulchellum* (Sw.) Druce, *Dianthus stenocalyx* Juz., *Inula helenium* L., *Iris pseudacorus* L., *Filipendula ulmaria* (L.) Maxim., *Caltha palustris* L., *Geum rivale* L., *Parnassia palustris* L., *Sanguisorba officinalis* L., *Valeriana officinalis* L.)

Keywords: natural habitats, the Uda River valley, Emerald Network, rare plants

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INTRODUCTION

One of the important properties of the ecological network, or even its attribute, which underlies the very concept of the ecological network, should be its transit concerning various elements of economic infrastructure, including their integral complexes, settlements. It can provide a certain composition of natural and economic factors within individual natural-territorial complexes. Such a combination should be treated primarily as a precedent for finding consensus and ways to harmonize between natural and anthropogenic. Based on the principles of human society's awareness of the need to yield to nature. Only this approach will provide the prospect of forming a balance between nature and the economy. Under such conditions, it is possible to establish a regime of inexhaustible use of nature and optimization of the environment.

The Uda River Valley serves as an ecocorridor and connects several BioCenters. It is one of the territorial units of the regional ecological network of the Kharkiv region. The natural complexes of the valley are promising for the development of the Emerald Network, so the public proposed to include it in the Emerald Network. Proposals for the feasibility of creating two objects "The upper part of the Uda river valley" (UA0000292, area 10550,6 ha) and "The lower part of the Uda river valley" (UA0000295, area 13,381.0 ha) were expressed and implemented. This article is devoted to the characteristics of natural complexes of the Emerald Network object "The lower part of the Uda river valley" (UA0000295).

The Udyansk regional eco-corridor passes through four districts and the city of Kharkiv. Its length is more than 100 km. Only seven key territories were identified within it by the developers of the econetwork of the Kharkiv region. Only two of them were characterized by a sufficient area (as for regional BioCenters) – the Zolochivsky landscape reserve (1,477.7 ha) and the Rogozyanske wetland (532 ha) reserved for the will [1]. Subsequently, to optimize the Udyansk Eco-Corridor, it was proposed to add five more key areas and change its configuration. In particular, the introduction of the territory around the source of the Uda River into the eco-corridor, as well as its expansion in the areas bordering the town of Zolochiv, was considered expedient, which would cover an extensive system of ravine with remnants of natural vegetation and forest belts outside the urban area.

The target attention of ecologists and environmentalists is focused on objects that form the part of the Emerald Network [2], or promising for its introduction, more and more often now. Considerable attention is paid to the exploration and study of rare and invasive plant species in the study of these objects [3-5]. Some publications related directly to the northeastern part of the Forest-Steppe, both certain objects of the Emerald Network and natural complexes outside them [6-8]. The typological and botanical characteristics of the forests of five objects of the Emerald Network of Ukraine were revealed: "Mozh River Valley" [9], "Dergachiv Forest" [10]. Information on the representation of endangered natural habitats in Europe in northeastern Ukraine has been summarized [7]. However, information of ecological and botanical character is insufficient, fragmentary, or completely absent in publications on most objects of the Emerald Network, which are located within the Kharkiv region. "The lower part of the Uda river valley" belongs to such objects.

The purpose of the study is to determine the environmental importance and significance of the object of the Emerald Network "The Lower part of the Uda River Valley" in botanical, forest typological and general ecological aspects.

MATERIALS AND METHODS

The materials for research were facts on forest management of Babayevsky forests, Vasyshchivsky forest of SE "Zhovtneve LH" and Krasnopolyansky forest of SE "Zmiivske LH"; archival data from the Department of Botany and Plant Ecology of V.N. Kharkiv National University Karazin; Personal geobotanical descriptions of plant communities for 2015-2019, reconnaissance data conducted by route method in July 2020. Primary geodata were obtained by the means of NexGISMobile mobile application. The QGIS Desktop 2.18.4 software was used for their internal processing.

An electronic resource was used to characterize terrain and altitude indicators [11] Google Maps and forest management data were used to measure the area of individual tracts and habitats. To analyze the types of forest vegetation conditions and forest types, a database of forest assessment indicators was formed of wood plots according to the data from forest evaluation descriptions of forest management materials. The analysis has been performed using MS Excel 2016. The collection of the herbarium and its processing was carried out according to standard methods. The names of the taxa were given according to "Vascular Plants of Ukraine. A Nomenclatural Checklist" [12]. Descriptions of vegetation areas with the participation of rare species were performed according to the generally accepted method. Sample plots were established within the natural limits of phytocenoses. Areas with an area of 30x30 m were selected for forest groups, for meadow-steppe, meadow and swamp – 5x5 m. In determining the types of habitat, the literary sources of the last years of publication were used [13; 14]. The analysis of the typological structure of forests was carried out according to the methods of the Ukrainian school of forest typology [15; 16].

RESULTS AND DISCUSSION

Among the six middle rivers of the Kharkiv region (Oskil, Udy, Lopan, Merla, Oril, Samara) it is the Uda valley of the river Uda that is a transit for the city of Kharkiv. The height of the water surface of the Uda riverbed is 94 m

above sea level in the city, at the confluence of the Lopan river. The height of individual surfaces of the root bank is up to 202 m above sea level. The Uda riverbed flows for more than 70 kilometers, traveling along a fairly wide valley until it flows into the Siverskyi Donets River at a water surface height of 87 m above sea level. This high enough indicator of the local basis of erosion contributes to the deep dismemberment of the adjoining regions and the formation of powerful modern sediments of loose rocks in the adjacent areas. According to the physical-geographical zoning scheme, this territory (Fig. 1) belongs to the physical-geographical district of Zolochiv-Chuguiv of the Kharkiv slope-upland region of the eastern Ukrainian land of the forest-steppe zone of the eastern European plain [17].

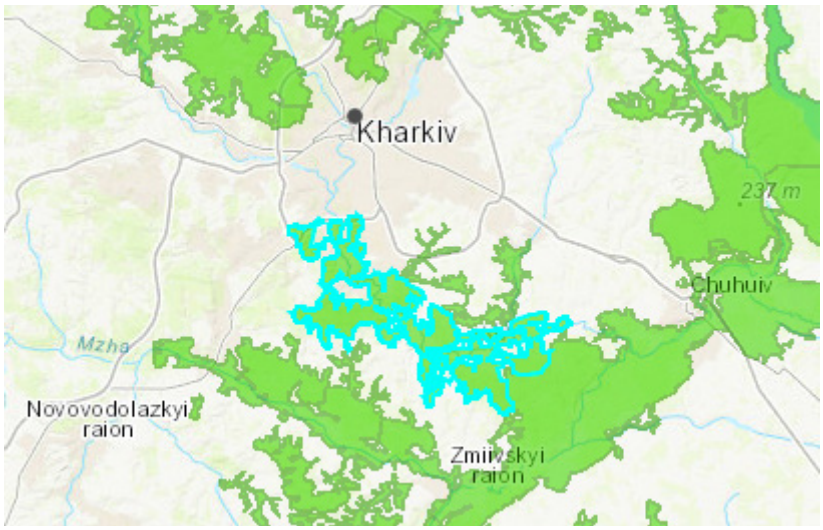

***Figure 1**. The scheme of the territory of the Emerald network object "The lower part of the Uda River Valley"*
***Source**: [18]*

In geomorphological terms, the territory of this Emerald object covers the floodplain surrounded by scattered segments of the pine terrace and the loess plateau. A well-defined floodplain stretches from the central parts of the city of Kharkiv to the confluence with the Siverskyi Donets River, having a diameter of 300 m, as within Kharkiv, up to 3 km, as in the area of Borova-Petrishcheve village and occupies a total area of about 3 thousand ha. The altitude of its surface varies from 95 to 100 m above sea level in the Babai village and from 87 to 92 m above sea level near the Eshar village. Below the Zhykhor residential district, various local depressions are widespread on floodplain extensions, such as weakly swampy lowlands and scattered low-flowing old lakes. One of the largest lakes is located north of the Gusyna Polyana village. It covers an area of up to 4 ha. Borovo-terrace plots are composed of ancient alluvial sand deposits reshaped from the surface by aeolian processes with surface heights in the range of 110-155 m above sea level adjacent mainly to the left bank. Significant areas are occupied by pine forests, the largest of which are located in particular to the south of the urban village Bezlyudivka and to the south-west of the urban village Vasyshchevo. As a result of sand mining on the site of old quarries, one of the largest artificial reservoirs has been formed in the city of Kharkiv, Nahorivske Lake. Together with the technical reservoirs (Kovalenky Lake), it covers an area of more than 100 ha. This Emerald Object should also include plots of the loess plateau. It is occupied by natural and semi-natural vegetation, in particular, deciduous forests of zonal type. These plots are mostly confined to the right bank by forested areas, in particular, south of the line of human settlements Borova – Krasna Polyana – Zaudie – Stara Pokrovka, Khoroshevo – Zhykhor – Gusyna Polyana.

The main types of plots within this area: floodplain areas with fresh and moist soils in modern alluvial-diluvial deposits. They are occupied by meadows, fragments of shrubs, forest vegetation, sometimes agrophytocenoses and fallows that have formed in their place. The pine terrace areas are made up of ancient alluvial sand from the surface complicated by aeolian sediments. They are dominated by artificial pine plantations; plots of the loess plateau with arable land and deciduous forests.

The total area of forested areas is 11,585 hectares. *Quercus robur* L. and *Pinus sylvestris* L. are the main forest-forming species. The first species occurs in an area of 8,091.5 ha, and the second 2,529.8 ha. Other species occupy small areas: *Populus tremula* L. (197.7 ha), *Acer platanoides* L. (186.7 ha), *Fraxinus excelsior* L. (129.6 ha), *Tilia cordata* Mill. (102 ha), *Betula pendula* Roth. (99.0 ha), *Acer campestre* L. (35.9 ha), *Alnus glutinosa* (L.) Gaerth. (35.8 ha), *Ulmus carpinifolia* Rupp. ex G.Suckow (30.8 ha), *Salix alba* L. (9.9 ha), *Populus alba* L. (6.9 ha), *P. nigra* L. (2.9 ha), *Malus sylvestris* Mill. (0.7 ha). An introductory species are the forest-forming species on the territory of 125.6 ha. This is approximately 1% of the total forest area. The largest

area is occupied by *Robinia pseudoacacia* L. (79.8 ha), less common are *Quercus rubra* L., *Populus deltoides* Marsh., *Fraxinus lanceolata* Borkh. (respectively, 22.4 ha, 13.4 ha and 8.2 ha). *Acer saccharinum* L. (1.5 ha), *Picea abies* (L.) H. Karst. (0.3 ha), *Juglans nigra* L. (0.2 ha) occupies a very small area.

Analysis of forest vegetation conditions revealed the following facts: the areas covered with forest vegetation are represented by 14 edatopes, covering all trophic groups and all levels of moisture, except for very dry areas (Table 1). At the same time, the largest area on the object territory of the studied object (96.4%) is occupied by forest areas, which are characterized by fresh moisture conditions. There are much fewer areas with dry conditions (2.2%), and only about 1.5% of the total area is accounted for by areas with damp, moist, and wet humidification conditions. At the same time, fresh and dry hygrotopes predominate under the conditions of the hruds, and under the conditions of the suhruds, subors – fresh and damp hygrotopes. In general, hruds account for three-quarters of the total area of forest. Subors account for almost one-fifth, and the least common are forests and suhruds, each with an area of just over 2%.

***Table 1**. Distribution of forest vegetation areas covered by edatopes*

Hihrotopy	Trophotopes				At
	A	B	C	D	
1	0.2	–	5.8	249.6	255.6
2	305.5	2,201.9	176.7	8,485.3	11,169.4
3	–	22.7	51.9	52.4	127.0
4	–	2.8	14.1	15.2	32.1
5	-	-	-	0.9	0.9
Total	305.7	2,227.4	248.5	8,803.4	11,585.0

For dry humidification conditions, typical forest types are eroded maple sudibrova and dry pine forest (5.8 and 0.2 ha, respectively). Wetlands are more diverse – black alder moist suhruds and hruds, wet hruds, as well as moist floodplain poplar-willow hruds (the part of the first three is 0.12%, 0.08% and 0.01% of the total area, the last – 0.05%). In humid floodplain wetting conditions, there are also areas of sedge subors and sudibrovy, each of which accounts for only 0.02% of the area. The fresh floodplain subsoil occupies 10.8 ha, which is 0.09%. The area of sudibrovs in fresh conditions of flooding of floodplain habitats is twice less than 4.6 ha. In damp humidification conditions on the area 23.4 ha maple-linden sudibrova is also presented. Linden-oak-pine suhrud is widespread in both fresh and damp hygrotopes (the area of the first 161.3 ha, the second only 26.6 ha).

In total, 21 forest types are represented on the forest vegetation-covered territory (Table 2). Maple-linden oak occupies three-quarters of the territory, with 8,485.3 ha of fresh maple-linden oak wood, dry – 249.6 ha, and damp oak wood occupies only 19.8 ha. A small area is also characteristic of damp linden-ash oak wood (32.6 ha) as well. At the same time, damp and moist oak-pine subir in the ratio of 9:1 are common only by 0.2%. The area of fresh pine woods is 305,5 ha.

***Table 2**. Distribution of the area of forested regions by forest types*

№ n / a	Names of forest types	Area, ha
1	Dry pine wood	0.2
2	Fresh pine wood	305.5
3	Fresh oak pine subir	2,201.9
4	Damp oak-pine subir	20.3
5	Damp floodplain sedge subir	2.4
6	Moist oak-pine subir	2.8
7	Dry eroded maple sudibrova	5.8
8	Fresh sudibrova	4.6
9	Fresh linden-oak-pine suhrud	161.3

Table 2, Continued

№ n / a	Names of forest types	Area, ha
10	Fresh floodplain sudibrova	10.8
11	Damp maple-lime sudibrova	23.4
12	Damp linden-oak-pine suhrud	26.6
13	Damp floodplain sudibrova	1.9
14	Moist black alder suhrud	14.1
15	Dry maple-lime oak wood	249.6
16	Fresh maple-lime oak wood	8,485.3
17	Damp maple-lime oak wood	19.8
18	Damp linden-ash oak wood	32.6
19	Moist black alder hrud	9.8
20	Moist floodplain poplar-willow hrud	5.4
21	Wet black alder hrud	0.9
Total		11,585.0

As mentioned above, within the study area, the main forest-forming species are *Quercus robur* and *Pinus sylvestris*. Analysis of the confinement of these species to certain types of edaphotopes revealed the following. *Quercus robur* stands for trophic conditions of habitats that occur mainly in oak wood (on an area of 8,040.9 ha), rarely in sudibrova (on 49.5 ha) and in fragments in forests (in 1.1 ha), and on humidity – mainly in fresh conditions (on an area of 7,812.3 ha), rarely in dry (230 ha) and damp (49.2 ha). *Pinus sylvestris* stands for trophic habitat conditions occurring mainly in subir (on an area of 2,155.1 ha), much less in pine wood (304.6 ha), quite rarely in suhruds (60.6 ha) and hruds (9.5) ha), and in terms of humidity, mainly in fresh conditions (on the area of 2,520.9 ha) and very rarely in damp (5.6 ha), moist (2.0 ha) and dry (1.3 ha). *Quercus robur* grows in 9 forest types, but the largest area of its stands is occupied by fresh maple-linden oak wood (7,786.6 ha) and much smaller in dry maple-linden oak wood (230,0 ha). *Pinus sylvestris* also grows in 9 forest types, but the largest area (2,147.5 ha) of its stands is occupied by fresh oak-pine subors, much smaller is occupied by fresh pine wood (304.4 ha) and fresh linden-oak-pine suhrud (56.0 ha). In other types of forests, the growing stock of these two species occupies small areas.

Currently, for the territory of the Kharkiv region, described 77 types of the level settlements of I-III level according to the EUNIS classification, which needs protection as components of the ecological network, nature reserve fund and the Emerald Network, and must be protected following Resolution No. 4 of the Bern Convention and the European Union Settlement Directive [7]. The study showed that within the object of the Emerald Network "The lower part of the Uda river valley" there are 14 types of settlements included in the list of objects (Table 3), the preservation of which in Europe requires the creation of special protection areas [13]. They are included in the list of objects for the preservation of which in Europe it is necessary to create areas of special protection [13].

***Table 3**. Settlements from Resolution 4 of the Bern Convention of the Emerald Network object "The lower part of Uda River Valley" (tabular data are filled in according to the methodology)*

Resolution 4 Habitat type			Site assessment			
Code	Cover [ha]	Data quality	A / B / C / D	A / B / C		
			Representativity	Relative Surface	Conservation	Global
C1.222	0.3	M	D	–	–	–
C1.32	5	M	D	–	–	–
C1.33	3	M	D	–	–	–
C3.34	0.5	M	D	–	–	–
D5.2	300	G	B	C	B	C
E2.2	500	G	B	C	C	C
E3.4	100	M	C	C	C	C

Table 3, Continued

Resolution 4 Habitat type			Site assessment			
Code	Cover [ha]	Data quality	A / B / C / D	A / B / C		
			Representativity	Relative Surface	Conservation	Global
F9.1	1	P	D			
G1.11	300	M	C	C	C	C
G1.41	25	M	C	C	C	C
G1.8	180	M	C	C	C	C
G3.4232	2500	M	C	C	C	C
G1.A4	250	M	C	C	C	C
G1.A1	8500	G	B	C	C	C

***Source**: [19]*

Settlements C1.222 – Free-floating monodominant clusters of Hydrocharis morsus-ranae occasionally occur in small fragments along shores and areas pond with slow-flowing waters. Variants of monodominant groups predominate, less often with insignificant participation in the cover of pleistophytes.

C1.32 – Free-floating vegetation of eutrophic reservoirs occurs everywhere in small areas throughout the Uda River. The shallow waters of the old floodplain lakes are characterized by much larger (up to several acres) areas of this vegetation, especially in the second half of the growing season. Most often, the main dominants of these groups are *Lemna minor* L. and *Spirodela polyrrhiza* (L.) Schleid. Sometimes colonies of filamentous algae play a significant role in such groups. Also common group with co-dominance of *Lemna trisulca* L.

The most typical variant of groups indicating habitats C1.33 (rooted submerged vegetation of eutrophic reservoirs), represented by thickets of *Ceratophyllum demersum* L. There are separate groups with a predominance of certain species of pondweed (*Potamogeton lucens* L., *P. perfoliatus* L., *P. gramineus* L.). Most often, the distribution of these settlements is characteristic of areas of the channel with slow flow and the waters of old lakes.

Eutrophic vegetation of slow-flowing waters (settlements C3.34) is most often represented by small fragments of groups dominated by *Nuphar lutea* (L.) Smith. and its distribution is similar to the previous ones. Aquatic habitats (category C) within this object of the Emerald Network occupy small total areas (Table 3).

Biotope (D5.2) – Lowland swamps with sedge and reed thickets without stagnant water often occur in the form of strips-borders adjacent to the riverbed in the floodplain depressions. During spring and summer floods, these areas are sometimes flooded. They are dehydrated most of the growing season. In some places, they are used for hay. A significant part of such settlements are groups dominated by *Phragmites australis* (Cav.) Trin. ex Steud. Groups dominated by *Carex acutiformis* Ehrh., *C. acuta* L. are also common. Populations of some rare species for the region and the European *Ostericum palustre* (Bess.) Bess., *Inula helenium* L. We found one of such habitats of *Ostericum palustre* in similar biotopes west of the village of Nahorivka in the meadows of the floodplain of the Uda River (49,864116 north latitude; 36,266887 east longitude).

Biotope E2.2 – Plain pastures are represented by floodplain pastures and pastures in large areas (Table 3). Large arrays of these meadows are distributed along the entire floodplain of the Uda River. The main dominants are cereals and sedges, such as *Arrhenatherum elatius* (L.) J. et al. Presl, *Alopecurus pratensis* L., Bromopsis erecta (Huds.) Fourr., *Dactylis glomerata* L. For areas with loose soils where until recently plowing was carried out, a characteristic predominance of long-rhizome grasses, such as *Elytrigia repens* (L.) Nevski, *Carex hirta* L., *C. praecox* Schreb., *Equisetum arvense* L., *Cirsium arvense* (L.) Scop. In plots with a high content of mobile nitrogen in the dominant role, there are representatives of forbs such as *Anthriscus sylvestris* (L.) Hoffm., *Pastinaca sativa* L. As co-dominants, most often grow, G*alium boreale* L., *Geranium collinum* Steph. In areas of mane elevations *Galium mollugo* L., *Scirpus sylvaticus* L., *Calystegia sepium* (L.) R. Br., *Lysimachia nummularia* L. *Linaria vulgaris* Mill., *Ambrosia artemisifolia* L., *Festuca valesiaca* Gaud., *Eryngium campestre* L. are more common.

Wet and damp meadows on rich silty soils with a predominance of forbs (biotopes E3.4) have been located along floodplain depressions, which are characterized by organogenic accumulation processes. They are characterized by groups of tall grasses from the wetland, dominated by species such as *Eupatorium cannabinum* L., *Sonchus palustris* L., *Urtica pubescens* Ledeb., *Bidens frondosa* L., *Leersia orizoides* (L.) Sw., *Angelica sylvestris* L., *Filipendula ulmaria* (L.) Maxim. The peculiarity of these habitats is the relatively high potential for the formation of phytomass, which dies mainly annually, and the poor availability or inaccessibility of its selection for economic needs. This is associated with a significant consortium-forming role of these habitats and the high species richness of phytophages in general and insects in particular. Together with the biotopes mentioned above, there is a complex of riparian shrub-forest biotopes (F9.1+G1.11). In elevated areas, groups with the

participation of *Prunus spinosa* L. often grow. Usually, the bushes tier is rather cover and is formed by thickets of thorny thorns with insignificant participation of *Fraxinus excelsior*. The grasses are almost absent due to the high shading of the shrub tier, but the most trivial species of meadow grasses grow in rarefaction. The most common variant of mesohydrophilic shrub vegetation in depressions is the group dominated by *Salix pentandra* L. with an admixture of *Salix cinerea* L. Fragments, sometimes significant in the area (up to ten acres) occur in willow-poplar forests of the riparian floodplain.

G1.41 – swampy alder forests on non-acidic peat are distributed here only in fragments. Alder nettles are their most typical variants. They grow in drying areas of terraced floodplain depressions. And alder sedge is confined to excessively and long-moist areas.

G1.8 – acidophilic oak forests are common in fresh and moist podzolic soils on the slopes of the pine terrace. Occur in fragments.

G1.A1 – deciduous forests in medium-rich and rich soils are widespread on the loess plateau and occupy large areas here (Table 3). A typical dominant in the upper tier is *Quercus robur*, and co-dominated by *Acer platanoides, A. campestre, Tilia cordata, Fraxinus excelsior*, sometimes *Ulmus laevis* Pall., *Pyrus communis* L. In the undergrowth tier, in addition to the undergrowth of the above-mentioned trees, shrubs grow, such as *Crataegus pseudokyrtostyla* Klok., *Euonymus verrucosa* Scop., *E. europaea* L., *Corylus avellana* L. The tier of grasses is sometimes weakly formed. *Aegopodium podagraria* L. and *Carex pilosa* Scop. are most often dominant in large areas. *Chelidonium majus* L., *Poa nemoralis* L., *Carex michelii* Host, *C. digitata* L., *Asarum europaeum* L., *Lathyrus vernus* (L.) Bernh., *Stellaria holostea* L., *Pulmonaria obscura* Dumort., *Polygonatum multiflorum* (L.) All., *Glechoma hirsuta* Waldst. & Kit., *Geum urbanum* L., *Mercurialis perennis* L., *Dactylis glomerata* L., *Lapsana communis* L., *Brachypodium sylvaticum* (Huds.) Beauv., *Fragaria vesca* L., *Viola hirta* L., *Lysimachia nummularia* L., *Lactuca chaixii* Vill. Grow everywhere as co-dominants and asectators. Among the ephemeroids identified by underground organs, *Corydalis solida* (L.) Clairv., *Ficaria verna* Huds.

G1.A4 – ravine and slope forests of natural and semi-artificial origin are represented by different coenotic variants of stages of demutation of forest vegetation. In particular, illuminated thermophilic forests with the dominance of *Ulmus carpinifolia* and significant participation in stands of such species as *Fraxinus excelsior* and *Pyrus communis* grow in the apical sections of the slopes. Separately, in the second tier, there are *Prunus spinosa* L., *Acer tataricum* L. In the grasses, the dominant *Poa angustifolia* L. is widespread. As codominants, *Hypericum perforatum* L., *Melampyrum nemorosum* L., *M. cristatum* L., *Centaurea substituta* Czer., *Betonica officinalis* L. *Potentilla obscura* Willd., *Poa compressa* L., *Rumex crispus* L., *Falcaria vulgaris* Bernh., *Trifolium montanum* L., *T. medium* L., *Eryngium planum* L., *Tanacetum vulgare* L. *Hieracium cymosum* L., *Vicia villosa* Roth, *Medicago falcata* L. aggr., *Daucus carota* L., *Elytrigia repens* (L.) Nevski, *Achillea millefolium* L. grow separately and with a covering of less than 1%.

G3.4232 – fresh and dry pines and subor of the Sarmatian type are confined to the highest areas of pine terraces. *Pinus sylvestris*, sometimes with significant participation of *Quercus robur*, is the main forest-forming species in sandy, slightly podzolic soils. In the second tier, you usually grow *Populus tremula, Quercus robur, Betula pendula, Sorbus aucuparia L., Acer negundo L.* In the poorly formed tier of undergrowth, all of the above species occur. Certain areas are also characterized by *Crataegus pseudokyrtostyla, Euonymus verrucosa, E. europaea*, and *Chamaecytisus ruthenicum* (Fisch. Ex Wol.) Klaskova, *Sambucus racemosa* L. The tier of grasses is usually poorly formed. The dominants include *Calamagrostis epigeios* (L.) Roth, *Poa nemoralis, P. angustifolia, Carex praecox* Schreb. Typical asectators in the grass level are *Pilosella echioides* (Lumn.) F.Schultz & Sch. Bip., *Hieracium umbellatum* L., *H. virosum* Pall., *Carex ericetorum* Poll., *Silene nutans, Polygonatum odoratum, Mycelis muralis* (L.) Dumort., *Senecio vulgaris* L., *Helichrysum arenarium* (L.) Moench. *Chamerion angustifolium* (L.) Pigeon. forms thickets in cluttered places and fires. Pure pine stands are often characterized by the development of moss synusias with a predominance of *Dicranum rugosum* and *Pleurocium shreberi*.

It should be noted that the object of the Emerald Network "Lower part of the Valley of the River Uda" has not only a certain synsozoological value but also considerable phytosozoological significance. In general, some species of plants are protecting at the national (*Botrychium lunaria* (L.) SW., *Dactylorhiza incarnata* (L.) Soo s.l., *Epipactis palustris* (L.) Crantz, *Anacamptis coriophora* (L.) R.M. Bateman, Pridgeon & M.W. Chase (*Orchis coriophora* L.), *A. palustris* (Jacq.) R.M. Bateman, Pridgeon & M.W. Chase (*Orchis palustris* Jacq.) and regionally (*Centaurium erythraea* Rafn., *C. pulchellum* (Sw.) Druce, D*ianthus stenocalyx* Juz., *Inula helenium* L., *Iris pseudacorus* L., *Filipendula ulmaria* (L.) Maxim., *Caltha palustris* L., *Geum rivale* L., *Parnassia palustris* L., *Sanguisorba officinalis* L., *Valeriana officinalis* L.) were found in the natural complexes of the Uda River Valley (in the middle course) [7; 9]. Special attention was paid to the study of local populations within the territory of Kharkiv of those species that are listed in the Red Data Book of Ukraine and have the status of vulnerable, in particular, conducted a phyto-indication assessment of growth conditions, established their compliance with ecological amplitudes of rare species. In the upper reaches of the Uda River in floodplain meadows on the left bank of Rogozyansky Reservoir, in addition to *Anacamptis palustris* and *Dactylorhiza incarnata* , the species *Dactylorhiza maculata* (L.) Soó sl. and *D. majalis* (Rchb.) P.F. Hunt et Summerhayes s.l. were detected. Data on the growth of certain orchid species in floodplain meadows in the lower reaches of the Uda River were presented. The identified species are listed in the Ukrainian Red Data

Book, in particular *Anacamptis palustris* and *Dactylorhiza incarnata* (near the urban village of Vasyshchevo) [20]. Together with the coenopopulations located on the floodplain of the upper Uda River [21], they form a single regional population.

CONCLUSIONS

The landscape complex of the lower part of the Uda River Valley has an important ecosystem potential that will contribute to the preservation of the natural complex of the studied region. This area includes tracts where populations of protected plant species are growing. Settlements from Resolution 4 of the Bern Convention are also presented in large areas of research. Within of the Emerald Network object "The Lower part of the Uda River Valley" 14 types of protected settlements are presented. Large areas are represented by biotopes with a predominance of grass (D5.2; E2.2; E3.4) and forest (G1.11; G1.8; G3.4232; G1.A1; G1.A4) vegetation. An important structural and territorial feature of this natural protection object is that it is an important connecting element of the ecological network of this urbanized region. The total area of forested areas is above 11,585 hectares. The main forest-forming species are *Quercus robur* and *Pinus sylvestris*. The areas covered with forest vegetation are represented by 14 edatopes, covering all trophic groups and all moisture levels, except for very dry ones. The largest area on the territory of the studied object (96.4%) is occupied by fresh humidification conditions, much fewer areas with dry conditions (2.2%) and approximately 1.5% of the total area is accounted for by areas with damp, moist, and wet humidification conditions. While the hruds relate to three-quarters of the total forest area, the forests account for almost one-fifth. The least common are pine wood and suhruds, the area of each of which is slightly more than 2%.

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Лісотипологічна та оселищна характеристика об'єкту Смарагдової мережі «Нижня частина долини річки Уди» в Харківській області

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Анотація. Висвітлено природоохоронну важливість і значимість Смарагдового об`єкту «Нижня частина долини річки Уда» (UA0000295) площею 13381,0 га в околицях м. Харкова в ботанічному та загально-екологічному аспектах. Досліджена територія поєднує ділянки заплавних знижень зайнятих луками, фрагментами чагарникової та лісової рослинності, масивами борової тераси із штучними сосновими насадженнями, а також ділянками лесового плато із орними землями та широколистяними лісами. Для Смарагдового об'єкту наведено перелік провідних видів рослин, площі та основні еколого-біотичні особливості виявлених оселищ з Резолюції 4 Бернської конвенції, зокрема C1.222, C1.32, C1.33, C3.34, D5.2, E1.2, E2.2, E3.4, F9.1, F3.247, G1.11, G1.21, G1.41, G1.8, G3.4232, G1.A4, G1.A1. Найбільші площі з них займають біотопи низинних боліт із заростями осок і очерету без застою води (D5.2), рівнинних сінокісних (E2.2) і мокрих та вологих лук із переважанням різнотрав`я (E3.4) та широколистяних лісів на середньо-багатих та багатих ґрунтах (G1.A1), а також свіжі і сухі бори та субори сарматського типу (G3.4232). Висвітлено лісотипологічне різноманіття території, причому площа вкритих лісовою рослинністю ділянок становить 11585,0 га. Основними лісотвірними породами є дуб звичайний (*Quercus robur* L.) (8091,5 га, 69,83 %) з переважанням у його насадженнях свіжої кленово-липової діброви та сосни звичайної (*Pinus sylvestris* L.) (2529,8 га, 21,84 %) з переважанням свіжого дубово-соснового субору. Ряд видів мають відповідний статус збереження в Україні (*Botrychium lunaria* (L.) SW., *Dactylorhiza incarnata* (L.) Soo s.l., *Epipactis palustris* (L.) Crantz, *Anacamptis coriophora* (L.) R.M. Bateman, Pridgeon & M.W. Chase (*Orchis coriophora* L.), *A. palustris* (Jacq.) R.M. Bateman, Pridgeon & M.W. Chase (*Orchis palustris* Jacq.), а ряд видів охороняються на регіональному рівні (*Centaurium erythraea* Rafn., *C. pulchellum* (Sw.) Druce, *Dianthus stenocalyx* Juz., *Inula helenium* L., *Iris pseudacorus* L., *Filipendula ulmaria* (L.) Maxim., *Caltha palustris* L., *Geum rivale* L., *Parnassia palustris* L., *Sanguisorba officinalis* L., *Valeriana officinalis* L.)

Ключові слова: природнє місцезростання, долина річки Уди, Смарагдова мережа, рідкісні рослини

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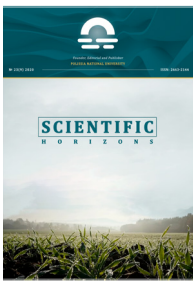

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Agroecological Bases of Sustainable Development Strategy for the Rural United Territorial Communities of the Western Polissya Region

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Abstract. The article considers the influence of agroecological indicators on the sustainable development of the rural united territorial communities of the Western Polissya region (Ukraine) based on the current state analysis of crop production. To study the state of crop production and determine its role in the development of rural areas of the Western Polissya region, the authors used their field research, as well as data from the Main Departments of Statistics in Rivne and Volyn regions, the State Statistics Service of Ukraine, statistical collection "Crop Production of Ukraine" (2018). The following methods were applied throughout the research process: system analysis, comparison, graphical and statistical methods. The development of crop production was assessed taking into account the dynamics of the following indicators: sown areas of crops (thousand hectares), production volume (gross harvest) of crops (thousand centners), crop yields (thousand hectares^{-1}), sown areas of crops in enterprises and households on the territory of the Western Polissya region in terms of Rivne and Volyn regions for the period from 1995 to 2019. During the study period, changes in the ratio of areas between different crops were discovered: a decrease in the sown area of sugar beet, fruit and berry crops, cereals and legumes, and an increase in sunflower, vegetable crops, etc. An increase in crop yields and a slight decrease in gross harvest were established only for sugar beet in the two regions and fruit and berry crops in the Volyn region. In the region, 51.6% of the sown area of crops is accounted for by households that supply the market with products included in the consumer basket of ordinary citizens: roots and tubers, vegetables, and melons. Enterprises are focused on growing profitable crops (technical, grain, and legumes) for export

Keywords: agroecological indicators, anthropogenic impact, sustainable development, rural united territorial communities, Western Polissya region

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INTRODUCTION

The authors observe the formation of a new worldview paradigm based on a political and practical model of development of all countries, which fulfills the current generation's needs without compromising the ability of future ones to fulfill theirs. This model is focused on achieving the optimal balance between the three development components – economic, social, and environmental. The transition to sustainable development is becoming an important objective for Ukraine as well, given the goals based on political, economic, social, environmental, moral, religious, ethnic, cultural, and sociological values inherent in Ukrainian society [1-3]. Therefore, to move towards sustainable development in Ukraine, the question of certain social transformations arose, one of which is the decentralization reform of the administrative-territorial organization.

In 2014 the implementation of decentralization reform was launched. The main objectives of this reform are the achievement of optimal distribution of powers between local governments and executive authorities on a subsidiarity basis, and creating viable territorial communities as a foundation for the new administrative-territorial organization. As part of the reform, the fundamentally new processes of cooperation and voluntary unification of territorial communities should take place. The purpose of such optimization is to create an effective system of public authority in administrative-territorial units. Such a system should be able to provide favorable conditions for human life and opportunities for sustainable socio-economic development of all regions via the rational use of their natural resource potential [4; 5].

At the time of writing, the united territorial communities are entering a new stage of their existence. They received authority, ability to distribute their own and obtain external resources. Created communities are responsible to their residents for creating a comfortable and safe living environment. This requires predictable and motivated development; its initial stage is in the development of strategic directions for sustainable development. It has become quite a challenge for the communities, whose population has been declining significantly in recent years.

An important factor in the sustainable development of rural territorial communities is the development of the agricultural sector, capable to ensure the food independence of Ukraine and provide a significant number of jobs for the population. As there are two main and closely interconnected branches in agricultural production – crop production and animal husbandry, their development becomes a strategic goal of agriculture. Thus, crop production is the basis for feed manufacturing and directly affects the development of animal husbandry. Furthermore, the waste generated in animal husbandry is an organic fertilizer, the introduction of which helps to increase soil fertility, the content of nutrients and stimulate the development of microorganisms, which makes it possible to increase plant yields [5; 6].

Under the strategic directions of agricultural development of Ukraine for the period up to 2020, the goal of the crop development strategy was to ensure a stable increase in production for the needs of the domestic and foreign markets and increase the efficiency of the industry. The main goals of crop development for this period were identified as follows: 1. Increasing crop production; 2. Creating a balanced feed base for livestock; 3. Creating a raw material base for bioenergy; 4. Increasing exports of crop products and products of its processing; 5. Increasing the productivity of crops [7].

The key issues considered in the study of the state and prospects of crop production include the impact of tillage and fertilization on yields, the formation of scientifically sound crop rotations, the introduction of innovations in crop production, breeding new varieties, protection of crops from weeds and pests, diseases, viruses, etc. Increasing crop yields makes it possible to obtain more products without changing the sown area, which is one of the priority goals of crop development, so many scientific works are devoted to solving this problem.

The main factors influencing crop yields, including natural factors of cosmic origin (solar activity and lunar cycles) are cited in the works of P. Pisarenko and Ya. Khlebnikova [8], G. Mühlbachová et al. [9], N. Lialina [10], and M. Mayerová et al. [11], who investigated the influence of chemical weed control agents on crop yields in different crop rotations. According to their data, crop losses in the uncontrolled area (control) increased in the following order: spring barley < winter wheat < peas < oilseed rape <potatoes.

Particularly relevant today is the impact of climate change on crop yields, that depend on climatic indicators, extreme temperatures, and carbon dioxide concentrations, which are expected to increase in the next century. D. Angelova [12], L. Petersen [13] proposed a model of approximate yield at the enterprise level in the context of climate change, which combines economic and agronomic concepts of crop production. L. Yu et al. investigated the impact of drought on crop water use efficiency [14]. O. Fraier emphasizes the need to strengthen agricultural diversification, i.e., by forming a balanced crop rotation portfolio with the addition of different crops [15].

It is now believed that any modern agricultural technology should be soil-protective – to ensure efficient use of land, as well as the restoration and increase of its fertility. The effectiveness of various agricultural technologies for growing crops is reflected in the studies by scientists from different countries. For example, V. Dnes et al., as a result of comparing the economic efficiency

of different technologies, have found that the use of no-till farming saves money almost two times, compared with differentiated technology [16]. The influence of different tillage systems on agrophysical parameters is provided by Y. Grechishkina et al. [17]. In recent years, the development of nanotechnologies, which are also used in agricultural production, has become more widespread. The production of nanoparticles attracted the attention of chemists and biologists, who want to use them to develop a new generation of nanofertilizers and nanopesticides. For example, M. Bayat et al. investigated the use of products based on agro-nanoparticles and their use to combat fungal diseases of strawberries [18].

An alternative management model, which involves the efficiency of agricultural production while reducing the anthropogenic load on the environment and natural resources, is the transition to organic agricultural production [19]. Organic agricultural production is consistent with the generally accepted concept of sustainable development in the world, as it provides stabilization and restoration of quality parameters of land resources. In addition, it guarantees the diversification of food types in the country and provides the population with quality food, opening the prospect of social and economic growth in rural areas through the export of certified products to world markets at much higher prices. T. Epule in his work compares the impact of organic and inorganic agriculture on global food security, where he points out that organic farming alone cannot support sufficient production [20]. According to him, a reasonable combination of organic and inorganic types of agriculture provides the best effect.

Thus, studies aimed at the development of the crop industry are actively continuing, and their introduction and use in enterprises, farms, and individual farms require funding and government support programs. Therefore, constant monitoring of crop production, which depends on many indicators that may change each year, does not lose relevance. This allows to identify strengths and weaknesses at the regional level, identify and work to reduce the main threats to its sustainable development to ensure a favorable investment environment. In addition, the development of agriculture is one of the priority goals of the Strategies of socio-economic development of rural and urban territorial communities that are currently in the final stages of formation (by the end of 2020) as a result of administrative reform launched in Ukraine in 2014.

The purpose of the study was to assess the impact of agri-environmental indicators on the sustainable development of rural integrated territorial communities of the Western Polissya region (Ukraine) based on the analysis of the current state of crop production.

MATERIALS AND METHODS

To study the state of crop production in the Western Polissya region, the dynamics of sown areas of the crops (sugar beet, sunflower, potato, cereals and legumes, vegetables, fruits, and berries), their production (gross harvest), and yield were analyzed. The data were analyzed for the period from 1995 to 2019 in terms of the Rivne and Volyn regions.

To determine the role of crop production in the development of rural integrated territorial communities, the ratio of sown areas of fodder crops, technical, grain and legumes, roots and tubers, vegetables, and melons in enterprises and farms in the region as of 2019. The study used data from the Main Departments of Statistics in Rivne [21] and Volyn [22] regions, the State Statistics Service of Ukraine [23], and the statistical yearbook "Crop Production of Ukraine" [24].

The article considers the ratio of crops in crop rotations under the approved standards of the optimal ratio of crops in different natural and agricultural regions (Table 1).

Table 1. *Standards for the optimal ratio of crops in crop rotations in different natural and agricultural regions*

Natural agricultural region	Structure of sown areas (in percent)							
	Cereals and legumes	Technical cultures			Vegetables, potatoes, melons	Fodder crops		Autumn fallow
		Total	Including			Total	Including perennial herbs	
			Rapeseed	Sunflower				
Polissya	35-80	3-25	0.5-4	0.5	8-25	20-60	5-20	
Forest-steppe	25-95	5-30	3-5	5-9	3-5	10-75	10-50	
North steppe	45-80	10-30	10	10	< 20	10-60	10-16	5-14
South-steppe (irrigation included)	40-82	5-35	5-10	12-15	< 20	< 60	< 25	18-20
Pre-Carpathian	25-60	5-10	5-7		8-20	25-60	10-40	

Source: *[25]*

The study used the following main methods: systematic analysis (the comprehensive analysis of the relationship between the area of crops and products), comparative (the general and distinctive features in the development of crop production in Rivne and Volyn regions in farms of all categories were determined), graphical method (for visual presentation of results), statistical method (for detection of changes in sown areas of crops, the volume of their production and productivity for the period from 1995 to 2019).

RESULTS AND DISCUSSION

The Western Polissya region, (also known as the North-Western region according to socio-geographical zoning), is located in the extreme North-West of Ukraine. It includes two oblasts, Volyn and Rivne, with a total area of 40.2 thousand km^2, and a population of 2.19 million people (Fig. 1).

In 2019, the share of regional rural residents was 50%. Due to the low level of urbanization, the average population density (54 people per km^2) is much lower than the national average, the lowest among all economic regions. There is a significant surplus of labor resources in the region, especially in rural areas. This leads to significant pendulum migrations and departure of residents for seasonal work both within Ukraine and in other countries.

Figure 1. *Western Polissya region on the map of Ukraine*

Natural and climatic conditions

According to the climatic zoning, the Western Polissya region is located in the North Atlantic-continental climate region. The climate is temperate continental: mild winters with frequent thaws, warm summers, average annual rainfall – 650-700 mm. Winter comes in late November, and a stable snow cover is formed in the last days of December – the first decade of January. Summer comes in late May and lasts until September. This is the period of the highest air and soil temperatures, precipitation, and ripening of the crop. Clear, cool early autumn weather sets in early September [26]. According to the physical and geographical zoning, the studied region is located on the East European Plain. The central and northern parts of the Western Polissya region are located in the zone of mixed (coniferous-deciduous) forests (Polissya region), Volyn Polissya region. The southern lands belong to the zone of deciduous forests (Western Ukrainian region), the Volyn upland region, and the extreme southern lands fall into the region of Small Polissya [26].

There are two distinct types of landscapes in the region – Polissya and forest-steppe. Polissya landscape areas are characterized by large forest cover, wetlands, spread over large areas of meadows (inter-river and floodplain), the predominance of infertile soils, and the presence of a significant number of floodplain and karst lakes. The main massifs are occupied by pine and pine-oak forests, small areas – hornbeam-pine, hornbeam-oak, and other forests. Bogs and wetlands occupy an average of about 10-20%, and in the northern regions up to 40% of the territory [27; 28].

The valley-ridge terrain complicated by ravine-beam and karst forms is inherent in forest-steppe landscape areas. The forest cover is smaller in comparison with the Polissya landscape, deciduous and mixed forests of oak, hornbeam, and pine predominate. Meadows in the forest-steppe part are almost completely flooded, less often located on the edges of swamps and beam bottoms. Swamps – lowlands, occupying the valleys of small rivers.

According to geobotanical zoning, the region is located in the European deciduous forest area (zone). The center and north are located in the Eastern European (Sarmatian) provinces of coniferous-deciduous

and deciduous forests, namely: Polissya sub-province of coniferous-deciduous forests, districts – Western Polissya oak-pine, pine, hornbeam-oak forests, and Verkhopripyatsky floodplains pine, alder, spruce (fragmentary) forests, floodplain meadows and oligo-, meso-, eutrophic bogs. The southern part of the Western Polissya region is part of the Central European Province of Deciduous Forests, the South Poland-Western Podolsk Subprovince of Deciduous Forests, Meadows, Meadow Steppes and Eutrophic Swamps, and the districts of Lublin-Volyn are hornbeam-oak, and Small Polissya hornbeam-oak, pine forests, floodplain meadows and eutrophic bogs [26].

According to the agro-climatic zoning, the Western Polissya region belongs to the zone of sufficient moisture, which is characterized by the following indicators: hydrothermal coefficient 1.3-1.6, the sum of active temperatures 2400-2800°C, the amount of precipitation for the warm period 360-430 mm, the length of the period active vegetation 160-175 days, duration without frosty period on the soil surface 140-170 days, reserves of productive moisture in a meter layer of soil, mm; a) under the chill in early spring (April 1) 160-220; b) before the cessation of winter vegetation on non-steam predecessors (November 1) 110-220 [26].

According to agro-soil zoning, the central and northern parts of the Western Polissya region are located in the zone of Ukrainian Polissya with sod-podzolic and swamp soils on ancient alluvial, water-glacial deposits, and moraines, a Western province with sod-podzolic, podzolic-podzolic, swamps, c. incl. peat soils. In the east, a small part of the region entered the Right Bank Province with sod-podzolic, mostly gleyed, swampy, including peat soils. The southern part of the region is located in the Forest-Steppe zone with typical chernozems, podzolic and degraded soils mainly on forest rocks, a Western province with podzolic in some places gley soils and typical chernozems. The extreme southern territory of the region (namely the Rivne region) is also part of the Ukrainian Polissya zone [26].

According to the agricultural zoning, the north of the Western Polissya region belongs to the intensive livestock area, characterized by meat and dairy cattle breeding, flax growing, potato growing, and the south of the region belongs to the intensive livestock farming area, which is dominated by beet growing, grain farming, m. meat and dairy cattle breeding, pig breeding [26]. In the structure of the land fund of the Western Polissya region, the total area of agricultural lands is 1974.2 thousand hectares, of which 1329.1 thousand hectares are arable land, 1176.2 thousand hectares are sown areas of crops (Table 2).

***Table 2**. Area of agricultural land in the Western Polissya region, thousand hectares*

	Total land area	Agricultural land	Arable	Sown areas of crops
Rivne	2005.1	926.2	656.8	587.6
Volyn	2014.4	1048.0	672.3	588.6
Western Polissya region	4019.5	1974.2	1329.1	1176.2

***Source**: calculated according to the State Statistics Service of Ukraine [23]*

According to the Main Department of the State Geocadastre in the Rivne region, the total area of its lands is 2005.1 thousand hectares. Agricultural lands occupy 926.2 thousand hectares (46.2%), of which 656.8 thousand hectares (32.8%) are arable land [27]. The land fund of the Volyn region as of 01.01.2019 is 2014.4 thousand hectares, of which 1048 thousand hectares (52%) are agricultural lands, which indicates a high level of agricultural land development. Arable land is 672.3 thousand hectares (33% of the total area) [28]. According to the State Statistics Service of Ukraine, the sown area of crops in these areas is 587.6 thousand hectares in Rivne and 588.6 thousand hectares in Volyn.

The state of crop production in the West Polissya region

Included in the strategy of socio-economic development of the united territorial communities of the Western Polissya region, the development of crop production as one of the key goals of sustainable development was analyzed taking into account the dynamics of the following indicators:

– sown areas of crops, thousand hectares;
– the volume of production (gross harvest) of crops, thousand centners;
– crop yields, $c \cdot ha^{-1}$;
– sown areas of crops in enterprises and households.

In 2019, 587.8 thousand hectares (50.0% of the total sown area) prevailed among the sown areas of crops, the industrial crops accounted for 255.3 thousand hectares), roots and tubers, vegetable and melon crops – 173.5 thousand hectares (14.8%), fodder crops – 159.6 thousand hectares (13.6%) (Fig. 2).

The dynamics of sown areas of some crops in the Western Polissya region in terms of regions for the period from 1995 to 2019 are shown in Table 2. The data given in Table 3 shows that for the period from 1995 to 2019 the sown areas allocated for crops in the regions underwent certain changes. For example, in the period from 2005 to 2019 the area for sunflower in the Volyn region has increased from 0.1 to 29.9 thousand hectares (approximately 290 times), and in the Rivne region in the same period it increased from 0.2 to 27.0 thousand hectares.

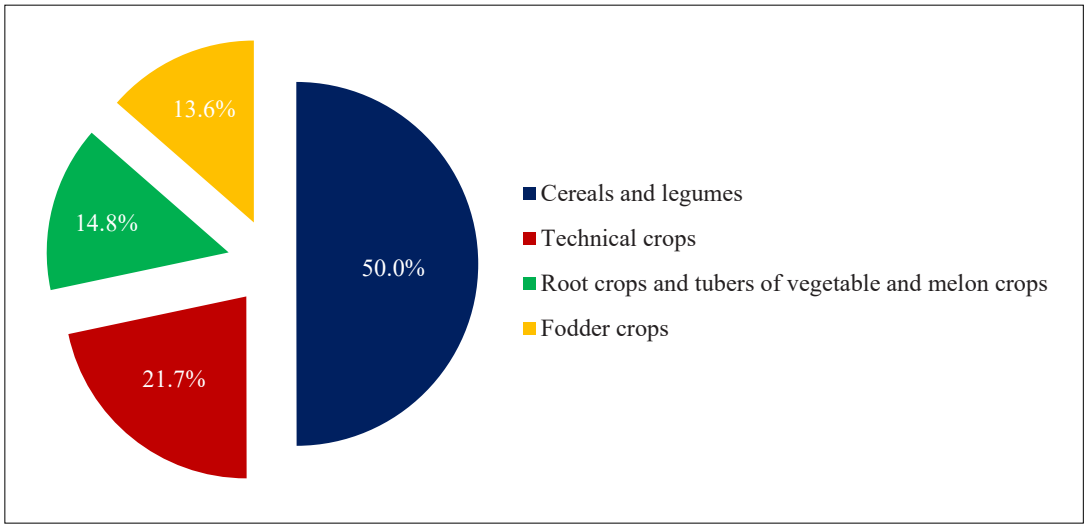

***Figure 2**. The ratio of sown areas of crops in the Western Polissya region in 2019, %*
***Source**: calculated according to the State Statistics Service of Ukraine [23]*

***Table 3**. Dynamics of sown areas of crops (updated) in the Western Polissya region in terms of regions for the period from 1995 to 2019, thousand hectares*

	Rivne region						Volyn region					
Years	Cereals and legumes	Sugar beet factory	Sun-flower	Potato	Vegetable crops	Fruit and berry crops (general)	Cereals and legumes	Sugar beet factory	Sun-flower	Potato	Vegetable crops	Fruit and berry crops (general)
1995	292.7	41.4	0.1	65.9	9.2	13.3	313.7	34.0	0.0	67.4	8.0	15.5
2000	270.8	24.9	0.1	74.0	10.1	9.0	271.8	29.4	0.0	79.3	10.5	5.4
2005	271.5	33.4	0.2	66.6	9.7	7.9	283.8	29.4	0.1	69.4	10.6	4.0
2010	244.2	30.8	2.7	68.7	10.9	7.6	242.1	16.3	0.2	65.9	11.7	4.1
2015	244.8	10.6	4.2	68.8	11.7	7.4	271.3	11.3	2.5	68.3	12.9	4.9
2016	270.0	11.9	15.1	69.9	12.0	7.0	295.5	13.5	6.4	72.0	13.1	4.9
2017	266.2	14.3	24.7	71.1	12.6	7.4	291.5	14.1	16.2	72.8	13.6	4.9
2018	262.1	13.7	24.2	70.9	12.6	7.4	293.8	12.2	23.6	76.5	12.9	4.7
2019	291.1	11.7	27.0	71.0	12.3	7.3	296.7	9.2	29.9	77.4	12.8	4.7

***Source**: formed according to the State Statistics Service of Ukraine [23; 24] and the Main Departments of Statistics in Rivne [21] and Volyn [22] oblasts*

Sown areas for potatoes and vegetables slightly increased in the regions. In the Rivne region in the period from 1995 to 2019, the area occupied by potatoes changed from 65.9 (1995) to 74.0 thousand hectares (2000), in 2019 this figure was 71.0 thousand ha. In the Volyn region in the same period, the area for potatoes almost did not differ from such of Rivne region and was in the range from 65.9 (2010) to 79.3 thousand hectares (2000), in 2019 – 77.4 thousand ha. Areas for vegetable crops increased in the Rivne region from 9.2 to 12.3 thousand hectares, in the Volyn region – from 8.0 to 12.8 thousand hectares, respectively.

As for the areas for cereals and legumes, fruits and berry crops, and sugar beet, there is a negative dynamic. For example, the area for cereals and legumes decreased by only 1.6 thousand hectares in the Rivne region and by

17 thousand hectares in the Volyn region, for beets from 41.4 to 11.7 thousand hectares (3.5) in the Rivne region and from 34.0 to 9.2 thousand hectares (3.7 times) in Volyn region respectively, for fruit and berry crops from 13.3 to 7.3 thousand hectares (1.8) in Rivne region and from 15.5 to 4, 7 thousand hectares (3.3 times) in Volyn region.

The change in the area for crops in the period from 1995 to 2019 in the region also affected the dynamics of their production (gross harvest), as shown in Table 4. The data in Table 4 shows, however, that the decrease in sown areas for cereals and legumes, sugar beet, fruit, and berry plantations had a negligible impact on production in the Western Polissya region for the period from 1995 to 2019, which associated with an increase in their yield (Table 4). The reduction of the gross harvest is observed only for sugar beet in the territory of two oblasts and fruit and berry crops in the territory of Volyn oblast. Thus, as a result of reducing the sown area for beets by 3.5-3.7 times, there was a decrease in gross harvest from 7629.5 thousand centners (1995) to 5600.8 (2019) in the Rivne region and Volyn – from 5966.7 thousand centners (1995) to 4117.3 thousand centners (2019). Reducing the area of fruit and berry crops in the Rivne region by 1.8 times did not affect the volume of production, but on the contrary in 2019, compared to 1995, the amount of gross harvest increased by 2.1 times. In the Volyn region, as a result of a 3.3-fold decrease in the area for these crops, a 1.4-fold decrease in production was detected.

***Table 4**. Dynamics of production (gross harvest) of crops in the Western Polissya region in terms of regions for the period from 1995 to 2019, thousand tons*

	Rivne region						Volyn region					
Years	Cereals and legumes[1]	Sugar beet factory	Sunflower[1]	Potato	Vegetable crops	Fruit and berry crops[2]	Cereals and legumes[1]	Sugar beet factory	Sunflower[1]	Potato	Vegetable crops	Fruit and berry crops[2]
1995	7552.6	7629.5	1.0	6483.6	1041.4	409.7	8189.0	5966.7	0.1	6215.5	1166.9	563.1
2000	4947.6	4313.8	0.6	8755.0	1336.5	346.8	5030.9	4862.8	0.1	11942.4	1105.5	386.2
2005	5991.6	5819.6	4.5	9120.3	1714.5	515.8	6770.5	7111.4	2.1	9752.0	2152.0	275.6
2010	6357.8	10105.1	29.8	10644.0	2164.7	859.1	5794.0	4736.4	2.2	9864.1	2486.6	342.4
2015	11015.4	4544.0	95.6	12275.8	2135.7	992.5	10622.8	4201.9	52.1	10988.1	2764.4	378.6
2016	13004.6	5438.8	370.4	12494.2	2362.3	776.9	11096.5	5803.9	155.8	11324.0	2887.4	370.4
2017	12087.2	6426.4	670.5	13109.1	2681.5	809.0	11652.0	6205.4	395.3	11394.6	3026.2	368.8
2018	12595.2	7239.0	584.2	13108.2	2651.0	871.8	12372.0	5283.3	695.2	11644.8	2802.2	428.7
2019	14930.1	5600.8	778.4	12847.0	2688.7	900.8	12926.3	4117.3	944.7	11741.7	2819.1	396.2

***Note**: 1 – in the mass after finishing, 2 – of the total area of plantings*
***Source**: formed according to the Main Departments of Statistics in Rivne [21] and Volyn [22] oblasts*

With a slight decrease in the area of grains and legumes, there is an increase in their gross harvest by 2.0 times in the Rivne region and 1.6 times – in the Volyn region. For other types of crops, the area of which in the region has been increased, there is an increase in production by two or more times. This is especially true for sunflower since the sown areas for it in the period from 1995 to 2019 increased and therefore its production also increased from 1.0 to 778.4 thousand centners in Rivne region, and from 0.1 to 944.7 thousand centners – in Volyn. The increase in crop production in the Western Polissya region is associated with an increase in their yield, the dynamics of which for the period from 1995 to 2019 is shown in Table 4. The data in Table 5 shows that over the last 24 years there has been an increase in yields of all these crops. Yields (centners per hectare) of fruit and berry crops increased 3.7 times in the Rivne region and 2.1 times – in the Volyn region, sunflower – 2.8 and 3.3 times respectively, sugar beet – 2.5 times in both regions. Slightly lesser results in the dynamics of crop yields can be observed in the potatoes, vegetables, grains, and legumes – around 1.6-2.0 times increase.

***Table 5**. Dynamics of crop yields in the Western Polissya region in terms of regions for the period from 1995 to 2019, thousands ha[-1]*

	Rivne region						Volyn region					
Years	Cereals and legumes[1]	Sugar beet factory	Sunflower[1]	Potato	Vegetable crops	Fruit and Berry crops[2]	Cereals and legumes[1]	Sugar beet factory	Sunflower[1]	Potato	Vegetable crops	Fruit and berry crops[2]
1995	26.0	191	10.1	99	116	35.6	26.5	182	9.0	93	150	44.6
2000	21.1	206	4.8	119	138	41.3	19.4	183	9.0	151	108	75.3
2005	22.6	176	25.7	137	176	69.8	24.1	246	13.7	141	203	76.8
2010	26.6	329	11.3	155	198	121.5	24.1	294	10.4	150	213	92.1
2015	45.0	429	22.8	178	183	145.4	39.4	371	20.6	161	215	87.6
2016	48.2	457	28.0	179	197	114.5	37.7	429	24.3	157	219	80.5
2017	45.7	449	27.3	184	212	119.0	40.1	442	24.7	157	221	81.4
2018	48.1	537	24.1	185	210	128.0	42.2	435	29.4	152	217	98.6
2019	51.2	479	28.1	181	213	133.3	43.4	446	30.1	152	218	95.03

***Note**: 1 – in the mass after finishing, 2 – from the area of plantations at fruiting age*
***Source**: formed according to the Main Departments of Statistics in Rivne [21] and Volyn [22] oblasts*

To determine the role of different types of farms in the development of agricultural production in the Western Polissya region as of 2019, the ratio of sown areas of crops for harvest in enterprises and households was analyzed. As a result of the analysis, it was revealed that 51.6% (606.9 thousand hectares) of sown areas of their total number (1176.2 thousand hectares) are located in households. The ratio of areas of different types of crops in the region in different types of farms is shown in Figure 3.

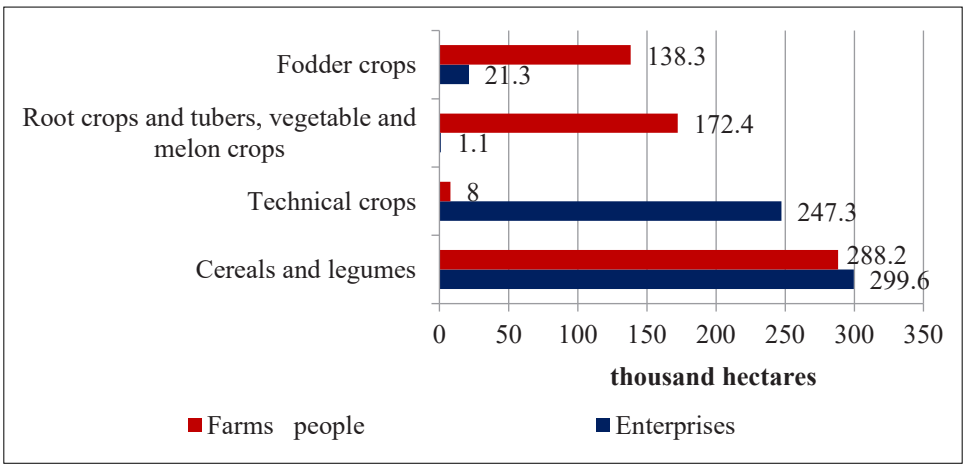

***Figure 3**. The ratio of sown areas of crops in enterprises and households in the Western Polissya region in 2019, thousand hectares*
***Source**: calculated according to the State Statistics Service of Ukraine [23]*

The data provided above leads to a conclusion that 49% (288.2 thousand hectares) of sown areas of cereals and legumes are in households, 51% (299.6 thousand hectares) – in enterprises, under industrial crops, respectively – 3 and 97%, roots and tubers, vegetables and melons – 99 and 1%, fodder – 87 and 13%.

During the research period in the Western Polissya region, changes in the ratio of areas between different crops as a result of a decrease in some (sugar beet, fruit and berry crops, cereals and legumes) and an increase in others (sunflower, vegetables, etc.) have been found. In general, the structure of sown areas of the region as of 2019 was dominated by areas occupied by cereals and legumes 50.0% (of the total sown area), industrial crops accounted for 21.7%, roots, tubers, vegetables, and melons – 14.8%, fodder crops – 13.6%. These rates are within the norms of the optimal ratio of crops in crop rotations of Polissya natural and agricultural region, except for fodder, according to which the percentage of cereals and legumes can be 35-80%, technical 3-25% (including rapeseed 0.5-4, sunflower – 0.5%), potatoes and melons 8-25%, fodder crops 20-60% (13.6% in the region) Figure 2 [29]. This ratio can be attributed to the profitability of growing various agricultural products.

According to O. Fraier [15], in recent years in Ukraine, there has been an increase in sown areas of four key commercially attractive crops (corn, sunflower, soybeans, rapeseed), while the share of other crops in the structure of sown areas of the corporate sector is rapidly declining. Thus, the most profitable types of agricultural production include the cultivation of sunflower, which can explain the significant increase in its area since 1995 in the Rivne region (270 times) and the Volyn region. Yields also increased by 2.8-3.3 times from 1995 to 2019. The area of its sowing in the structure of industrial crops was 22%, which indicates non-compliance with the norms of the optimal ratio of crops in crop rotations of Polissya natural-agricultural region, according to which the percentage of sunflower among industrial crops should be 0.5%.

Currently, this problem is quite common in Ukraine. According to V. Puzik et al. it is especially acute in Zaporizhia, Luhansk, Dnipropetrovsk, Donetsk, Mykolaiv, Kirovohrad, Kherson and Kharkiv regions [30]. The obtained products of the oil subcomplex are more export-oriented, which is the reason for the extensive growth factor of sown areas. The key concern of further development of oilseeds production is to increase and stabilize production volumes by optimizing sown areas. In addition, some farmers grow sunflower for several years on the same land plots to make more profit, although the allowable frequency of its cultivation according to current regulations in Ukraine is not less than seven years [15; 31]. Profitable crops include cereals, for which most of the sown area of the region is allocated. During the study period from 1995 to 2019, the area under cereals and legumes just slightly decreased, which did not affect the volume of production (gross harvest), but on the contrary, due to the increase in their yield from 26.0 to 51.2 c/ha the figure increased by 1.6-2.0 times. This indicates a transition to intensive technologies for growing these crops with increasing mechanization, chemicalization, and use of high-yielding and resistant to adverse environmental factors varieties and hybrids [32-34].

In recent years, the areas set aside for vegetable crops are quite stable, which from 1995 to 2019 increased by 7.9 thousand hectares (Rivne region – 3.1 thousand hectares, Volyn – 4.8 thousand hectares), yields increased 1.8-1.5 times. This indicates that the vegetable market in the region is developing. According to L. Galat and L. Yatsyshina, vegetable growing in Ukraine has remained a profitable industry for many years, because with the right approach to production, marketing, logistics, you can earn income even in conditions of overproduction and market decline [35; 36]. Therefore, the vegetable market, despite various negative factors, is developing, improving, and gradually showing signs of moving towards a civilized global market. It should be noted that the improvement of vegetable growing requires certain measures like breeding and seed production. This is because the variety and high-quality seeds are the main elements of modern zonal technologies for growing crops [37].

One of the most widely consumed foods on the daily basis is potatoes. In the region, potato growth is not developing rapidly. The sown area for potatoes in 2019 compared to 1995 increased slightly, but the production (gross harvest) significantly increased from 6215.5 to 12874.0 thousand centners in the Rivne region and from 6215.5 to 11741.7 thousand. c – in Volyn, which is due to an increase in yield from 93 g/ha to 181 (1.6-1.8 times). It should be noted that the potato market has certain features: the entrance is quite capital-intensive (there is a need for specific vehicles), and yield depends on climatic conditions, use of regional varieties, seed productivity, fertilizer systems, etc. [38-40].

The area for sugar beets in the West Polissya region decreased significantly by 3.5-3.7 times, which led to a decrease in the gross harvest from 7629.5 thousand centners (1995) to 5600.8 (2019) in the territory Rivne region and Volyn – from 5966.7 thousand centners (1995) to 4117.3 thousand centners (2019). It should be noted that the yield has increased 2.5 times over the past 24 years. The production and sale of sugar beets is the only industry that periodically, with an interval of one or two years, brings losses [10]. Long-term research and analysis of information on sugar beet productivity in retrospect according to V. Hlevasky et al. show that the dynamics of yield and sugar content of root crops is influenced by a set of conditions, some of which are uncontrolled at a high level of agrobiological and technical capabilities of human society [41]. Therefore, when growing sugar beets, it is necessary to focus on hybrids and seeds, cultivation technologies, sowing density, the presence of weeds, pests, diseases, and weather conditions of the growing season. High productivity can be obtained only when sowing high-quality seeds [42; 43].

During the research period in the Western Polissya region area for fruit and berry crops decreased by 1.8 (Rivne region.) and 3.3 times (Volyn region). As for the above-mentioned crops, the yield growth from 35.6 to 133.3 c/ha was observed during the study period.

As a result, the volume of their production (gross collection) increased in the Rivne region from 409.7 to 900.8 thousand centners but decreased from 563.1 to 396.2 thousand centners. due to the reduction of the area – in Volyn.

In the region, work has begun on the development of organic farming, in particular in the Volyn region 18 certified operators are specializing in the cultivation of crop products, berries, mushrooms, etc., the quality of which is confirmed by the recognition in the European Union and Switzerland certificate "Organic Standard". In this region, organic products are grown on an area of 2.1 thousand hectares, which is 0.2% of agricultural land in the region. In the Rivne region, businesses have certified organic agricultural products in most crops such as soybeans, buckwheat, corn, oats, wheat, sunflowers, vegetables, berries, and others. The area on which organic products and raw materials are produced is 4.2 thousand hectares, 0.5% of the total area of the region. Thus, the West Polissya region has significant potential for the development of organic farming, favorable natural and climatic conditions, so the Strategy of socio-economic development of rural integrated territorial communities includes the allocation of relevant areas of agricultural land.

The sown areas of crops in Ukraine are divided between enterprises and households. This is due to the land reform of 1991, according to which the lands of collective farms and state farms were privatized with their subsequent unbundling, the issuance of state acts on the right of private ownership of land (shares), and the right to withdraw from agricultural formations with shares. In the study region, 51.6% of the sown area of crops falls on households. In terms of different types of crops, the following ratio was found: 49% of the sown area of cereals and legumes is in households, 51% – in enterprises, under industrial crops, respectively – 3 and 97%, roots and tubers, vegetables and melons – 99 and 1%, fodder – 87 and 13%. This distribution shows, however, that companies are focused on growing profitable crops (technical, grain, and legumes) that are exported. Households supply the market with a set of products that are included in the consumer basket of ordinary citizens.

CONCLUSIONS

As a result of the analysis of the impact of agroecological indicators on the sustainable development of rural united territorial communities of the Western Polissya region, on the example of the study of crop production, the authors discovered both the formation of threats to their development and some promising opportunities. Agroecological threats to development include changes in the structure of sown areas of crops (reduction of areas and exclusion from crop rotation of crops typical for this region), excessive intensification of production, violation of standards for optimal crop rotation.

The promising opportunities of the region include:

– increasing the area of agricultural land for organic products, with favorable natural and climatic conditions, being a prerequisite for that;

– supporting the development of individual farms that largely meet the demand of the population in many goods and services. Encouraging the population to process their agricultural products for sale and create a market for it;

– forming of cluster models of development of newly created communities to increase the efficiency of use of production, trade, labor, innovation, investment, and information potential of the territorial community. One of the priority areas in the region of clustering in crop production can be considered the grain sector;

– developing and implementing short-term and long-term local and regional programs of the revival of components of agrolandscapes, to allocate "ecologically pure" raw material zones;

– taking into account the requirements of the EU Water Framework Directive to build water and soil protection engineering and landscape complexes at water intakes with the addition of forest, shrub, and meadow-swamp phytocenoses, creating in river basins (basin management principle) the optimal ratio between water lands and nature reserve fund;

– carrying out renaturalization of disturbed lands and their conservation to create meadows and forests for water protection, and include them in the structural elements of the regional ecological network based on an agro-environmental approach.

It should be noted that to implement the opportunities for agricultural development in rural UTCs it is important to create a favorable financial and credit environment that will allow introducing innovative technologies to agricultural production based on rational land use; to promote and support the manufacture of environmentally "friendly" products.

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Агроекологічні основи стратегії сталого розвитку сільських об'єднаних територіальних громад Західно-поліського регіону

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Анотація. У статті розглянуто вплив агроекологічних показників на сталий розвиток сільських об'єднаних територіальних громад Західно-поліського регіону (Україна) на основі аналізу сучасного стану рослинництва. Для дослідження стану рослинництва та визначення його ролі у розвитку сільських територій Західно-поліського регіону використано дані Головних управлінь статистики у Рівненській і Волинській областях, Державної служби статистики України, статистичного збірника «Рослинництво України» (2018). У процесі дослідження використовувалися такі основні методи: системний аналіз, порівняння, графічний і статистичний методи. Проаналізовано динаміку таких показників: посівні площі сільськогосподарських культур (тис. га), обсяг виробництва (валового збору) сільськогосподарських культур (тис. ц), урожайність сільськогосподарських культур (ц·га$^{-1}$), посівні площі сільськогосподарських культур у підприємствах та господарствах населення на території Західно-поліського регіону у розрізі Рівненської та Волинської областей за період з 1995 року по 2019 рік. За досліджуваний період виявлено зміни у співвідношенні площ між різними сільськогосподарськими культурами: зменшення посівних площ буряка цукрового фабричного, плодових і ягідних культур, зернових і зернобобових та збільшення – соняшника, овочевих культур тощо. Встановлено зростання урожайності сільськогосподарських культур та незначне зменшення валового збору лише для буряка цукрового фабричного на території двох областей та плодових і ягідних культур на території Волинської області. У регіоні 51,6 % посівної площі сільськогосподарських культур припадає саме на господарства населення, що постачають на ринок набір продуктів, які входить до споживчого кошика простого громадянина: коренеплоди та бульбоплоди, культури овочеві та баштанні. Підприємства зорієнтовані на вирощування рентабельних культур (технічних, зернових та зернобобових), що ідуть на експорт

Ключові слова: агроекологічні показники, антропогенний вплив, сталий розвиток, сільські об'єднані територіальні громади, Західно-Поліський регіон

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Anti-Crisis Stability of Break-Even Development Potential and its Resource Support in Agribusiness

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Abstract. The article considers the anti-crisis stability of the potential of break-even development and its resource support in agribusiness. The necessity of a synergetic approach to estimating the dynamic flow of resources capable of generating own sources of financing to activate the target parameters of crisis stability of break-even development potential and the development of an alternative scenario of self-financing of the production and financial cycle to stimulate economic growth of agribusiness is proved. The reproductive process of resource support of anti-crisis stability of the potential for safe development of agribusiness enterprises is substantiated. The model of estimation of target parameters of anti-crisis stability of potential of unprofitable development of agrarian business and a matrix of its point estimation at a choice of the alternative scenario of self-financing is presented. Scenarios of the flow of resource support of anti-crisis stability of the potential of unprofitable development of the agribusiness enterprise are developed. An indicator of the level of anti-crisis stability of the break-even development potential according to the determined target parameters of self-financing is offered. The dynamics of anti-crisis factor load on the stability of the potential of break-even development of agribusiness enterprises on average in one region of the Steppe zone of Ukraine by its territorial location is analyzed. Cluster analysis was used to assess the elements of the qualitative system-resource component of anti-crisis stability of the potential of break-even development with the separation of types of agribusiness enterprises in the regions of the Steppe zone of Ukraine with different structure of current assets. The forecast level of resource support according to the quantitative component of anti-crisis stability of the potential of break-even development on average in the regions of the Steppe zone of Ukraine and per one agribusiness enterprise of the region is determined. The forecast range of limits of target parameters of self-financing and their influence on the level of anti-crisis stability of potential of unprofitable development of agribusiness enterprises on the average on one region of the Steppe zone is presented

Keywords: anti-crisis stability, resource support, solvency, profitability, self-financing, break-even development

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INTRODUCTION

Expanding the capabilities of agribusiness enterprises in the new paradigm of anti-crisis system of their operation, with increasing impact on the state of reorganization in conditions of uncertainty and risk, allows distributing the available resource component in a continuous stream of expanded reproduction of agricultural production, directing own and involved sources on improvement of the growth rates of profitability. However, along with the objective reasons for this phenomenon, recently there are unfavorable global trends in the agricultural sector of the economy, which are associated with the crisis financial condition of economic entities, the basic principles of which are purposefulness, systematization and participatory anti-crisis stability.

Reforming agriculture in the world makes this problem relevant and necessitates the identification of effective scientifically sound models of the reproduction process of resource provision on the basis of systematization of indicators of crisis stability potential of break-even development of agribusiness enterprises adapted to exogenous economic factors. This requires diagnosing the economic security of agricultural enterprises, which should be based on a program-targeted approach to the reproduction of stable economic growth, balancing the production and financial cycle, accumulation of own resources through additional capitalized reserves and effective cash flow management with limited external sources. Objectively, this is due to the emergence of a multi-stage movement of cash flows of enterprises, as a result of which their connection with the material basis becomes more noticeable. The impact of the resource component on material production is justified, but at the same time, its irrational involvement in the operational and financial cycle can lead to unstable development of agricultural production as a whole. This leads to the search for ways to improve structural changes in the internal business environment, which enhances the anti-crisis stability of the potential of break-even development, reconciling the proportionality of material, financial and cost processes of reproduction of agricultural production.

The starting point of anti-crisis stability of the potential of break-even development of agribusiness should understand its rational structure, basic parameters, priority functions that can withstand the changing factors of the external business environment, guarantee solvency and investment attractiveness of businesses in the long run. At the same time, the agricultural sector lacks clear tools for preventive protection of agribusiness enterprises, which would unite their functional subsystems, eliminate threats to economic security and systematize the structural components of anti-crisis stability of break-even development potential at different stages of its life cycle.

Recently, the attention of scientists has been focused on the prevention of deep and prolonged crises, in particular: issues of the formation and development of bankruptcy prevention systems – V. Bdzhola [1], A. Belikov, G. Davyidova [2], L. Dovhan [3], Ya. Dropa [4], H. Ostrovska, O. Kvasovskyi [5], O. Raievnieva, M. Berest [6]; identification of non-financial factors of crisis development – M. Berdar [7], S. Borozdin, A. Maksimov [8], J. Bundy, M. Pfarrer, C. Short, W. Coombs [9; 10], B. Forgue [11], N. Hrapko [12], O. Komelina, A. Chaikina [13], V. Kovalenko, M. Suhaniaka, V. Fuchedzhy [14], O. Raievnieva, O. Horokhova [15]; ensuring the economic security of agribusiness enterprises – L. Havatiuk, N. Perehiniak [16], I. Kreidych, A. Haharin [17], N. Plakhotna [18], as well as the functioning of agricultural enterprises in the system of sustainable safe development – N. Kovalenko, N. Hontova [19], S. Mushnykova [20], D. Naipak [21], A. Pushkar, A. Trided, A. Kolos [22]. The theory and methodology of crisis management, which aims to increase the sustainability of business entities, have been studied by such scientists as: A. Azarova, O. Ruzakova [23], I. Blank [24], T. Hovorushko, N. Klymash [25], V. Makhovka [26], J. McTaggart, P. Kontes, M. Mankins [27], A. Rappaport [28], L. Starchenko, O. Starovoit, I. Semydotska [29], G. Stewart [30]; methodology aspects of the formation of anti-crisis stability of the potential for safe development of agricultural enterprises were studied by – G. Arnold, M. Davies [31], O. Honcharenko [32], L. Lihonenko [33], V. Mishchenko, O. Drougova, I. Domnina [34], V. Mishchenko, I. Sitak, I. Domnina [35]. However, the issue of complex interrelation of system-resource component of anti-crisis stability of potential of safe development of agribusiness enterprise on the basis of analytical-mathematical tools of estimation and diagnostics of researched processes remains insufficiently investigated.

The priority of our study is to develop a synergetic approach to assess the dynamic flow of resources capable of generating own sources of funding to activate the target parameters of crisis stability of break-even potential and develop an alternative scenario of self-financing of the production and financial cycle to stimulate economic growth of agribusiness enterprises.

MATERIALS AND METHODS

In a market economy, the stability of the potential of break-even development of the enterprise must ensure internal harmony, as well as compliance with the economic system, an element of which it is. The system is considered as a means that enables the functioning of an individual entity with the help and under the influence of environmental factors, which evolves and acquires new qualities, transforming the structure of the system [36]. Defining the economic aspects of the system, it should be noted that it changes over time only its status and not its essence, allowing a certain ordering of the components of the system that form a set that operates, functions, i.e. is viable. Depending on the connections that exist between the structural elements of the integrity, the resource content of the system is formed. The system can be represented by an element-resource

component on the basis of functioning of anti-crisis stability of break-even development potential, which makes it possible to comply with certain rules that play the role of limiting factors [37], turning the relationship of aggregate elements into an effective system. Given that each stage of economic growth of agribusiness is a stable system, which is determined by the potential interconnection of sources of financing of the entity, then the crisis stability of the potential of break-even development in its environment causes a constant exchange of system resources. The value of a particular type of resource in different systems varies, but an indisputable feature of the development of the system, both hierarchically and in time, is to ensure the sustainability of economic entities. Therefore, the anti-crisis stability of the potential of break-even development of agricultural enterprises must be considered taking into account the possibility of forming their own and borrowed resources from the external surroundings of the business environment.

From the standpoint of the structure of anti-crisis stability of the potential of break-even development of agribusiness enterprises, a set of internally interconnected parts is distinguished, the main elements of which are objects: production, marketing, finance, information, human resources. Hence, the subsystem objects of anti-crisis stability of break-even development potential are proposed to be defined as a set of resources that determine the relationship between the procedures of anti-crisis decisions to generate financial resources under constant changes in external and internal business environment. The reproductive process of resource support of anti-crisis stability of the potential of break-even development is inherently dynamic-cyclical in nature, the duration of which is at least a year. That is, depending on the anti-crisis development programs of agricultural sectors, the process of long-term (continuous) reproduction of the resource support of economic entities in space and time is provided (Fig. 1).

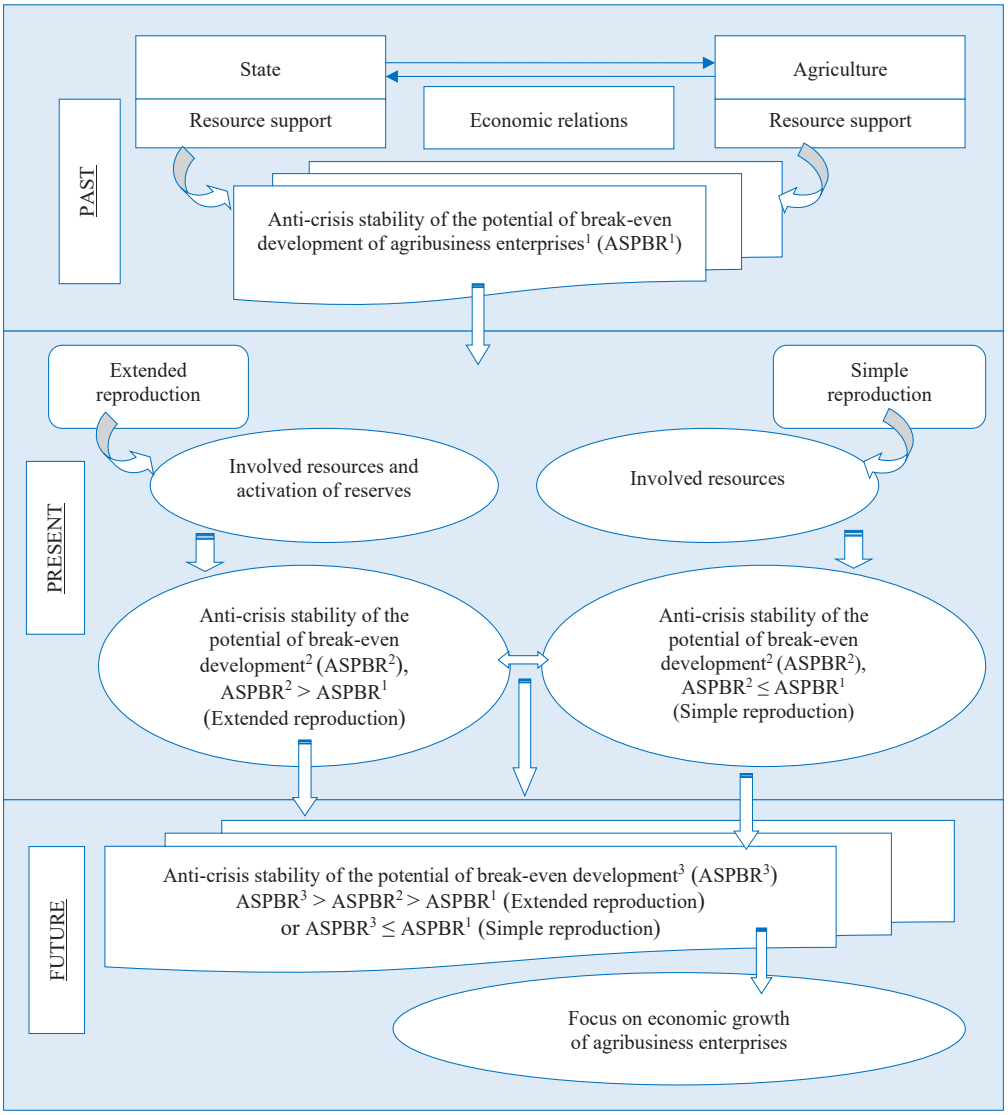


Figure 1. *Reproductive process of resource support of anti-crisis stability of potential of safe development of agribusiness enterprises*

Source: *developed by the authors*

Thus, from the point of view of the past, the level of anti-crisis stability of the potential of break-even development is determined by the set of resources mobilized by agribusiness enterprises and is characterized as achieved ($ASPBR^1$). Depending on the areas of the use of anti-crisis sustainable potential, namely: simple or extended reproduction of its resource support, it is possible to allocate, exchange and use resources; the resources used in the past activate the reserves to determine the current level of crisis stability of the break-even potential ($ASPBR^2$). Thus, the current level of crisis stability of the break-even potential can be reproduced both at the stage already reached or below it ($ASPBR^2 \leq ASPBR^1$), and at a higher stage of growth ($ASPBR^2 > ASPBR^1$).

Thus, the restoration of quantitative and qualitative system-resource component of anti-crisis stability of break-even potential, based on the implementation of the amplitude of resource support, activates existing reserves by choosing anti-crisis areas of enterprise development in the business environment, allowing to stimulate capital investment growth, accumulation of productive capital in the objects of investment reproduction in order to make a profit and (or) achieve a positive effect. At the same time, the state regulation of resource support of anti-crisis stability of break-even development potential will allow to reproduce the expanded reproduction by providing state guarantors with time limitation of budget financing in the investment activity of economic entities and to determine their potential state of economic growth in order to eliminate the shortcomings of the current procedure for selecting alternative innovative development and obtaining the expected effect, without losing the interest of enterprises in the reproduction of fixed capital. Therefore, the future state of anti-crisis stability of the break-even potential should be defined as promising ($ASPBR^3 > ASPBR^2 > ASPBR^1$), i.e. one that is focused on achieving a higher level. However, as already mentioned, depending on the conditions and results of the agribusiness in previous periods, its future state may be characterized by a simple reproduction of resource support ($ASPBR^3 \leq ASPBR^1$). The authors assume that break-even is the initial factor of the critical value of the financial balance between own and borrowed resources, which reflects the level of stability of the break-even potential of the enterprise. Prolonged stay of the company in the loss zone leads to the loss of a significant amount of equity, resulting in a reduction in current assets (a qualitative component of sustainable break-even potential), and as a consequence of working capital required for production activities. Accordingly, this situation leads to an increase in borrowed resources and characterizes the crisis environment of the enterprise. In this case, it is necessary to convert the lost capital from a negative value to zero to balance the resource support of property and anti-crisis development of the enterprise. With the advent of profits, equity is gradually formed, which is used to finance assets, ensuring anti-crisis stability of the potential of the entity. We believe that break-even is a financial platform for anti-crisis stability of the development potential of the enterprise by covering the loss of assets with equity, and balancing the liquidity limit as a value capable of exchanging and maintaining the value of accumulated assets, their transaction through increasing solvency (Fig. 2).

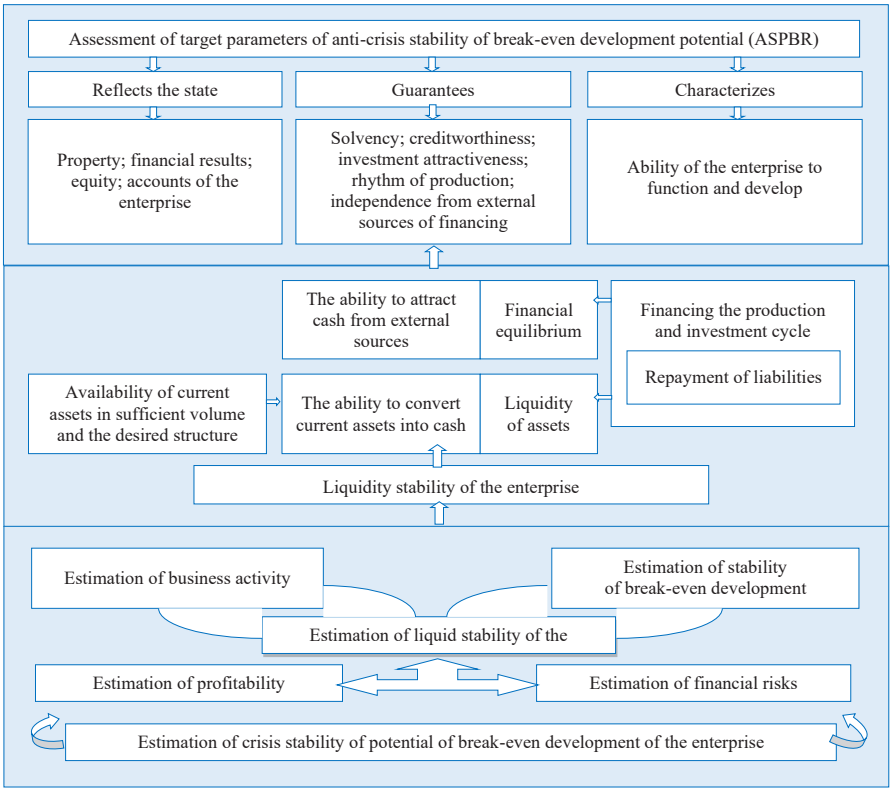


***Figure 2**. The model of estimation of target parameters of anti-crisis stability of potential of break-even development of the enterprise of agrarian business*

***Source**: developed by the authors*

The target indicators of anti-crisis stability of break-even development potential, under the influence of external and internal business environment allow determining a sufficient level of resource support of production activities and long-term expansion of investment opportunities of the enterprise with increasing profit and equity, maintaining the regulatory value of solvency and creditworthiness with a minimum level of financial risk [38; 39].

This leads to the change in the parameters of the basic flows of resource support and their impact on the solvency of economic entities (Fig. 3).

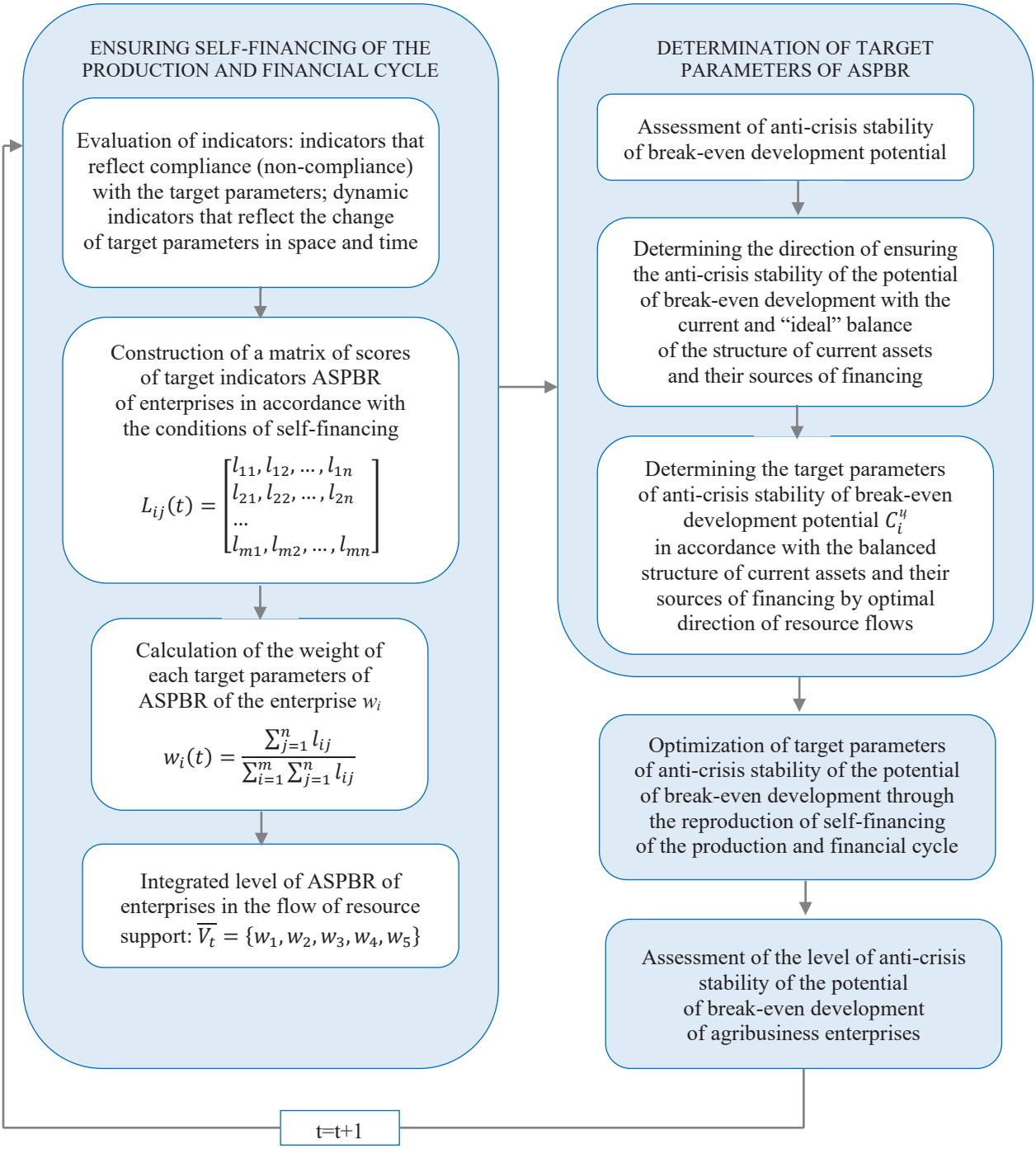


***Figure 3**. Algorithm of systematic estimation of target parameters of anti-crisis stability of potential of break-even development of the agribusiness enterprise*

***Source**: developed by the authors*

The embodies an effective matrix of possible scores of target parameters of anti-crisis stability of break-even potential in agribusiness through the reproduction of the vector of self-financing of the production and financial cycle (Fig. 4).

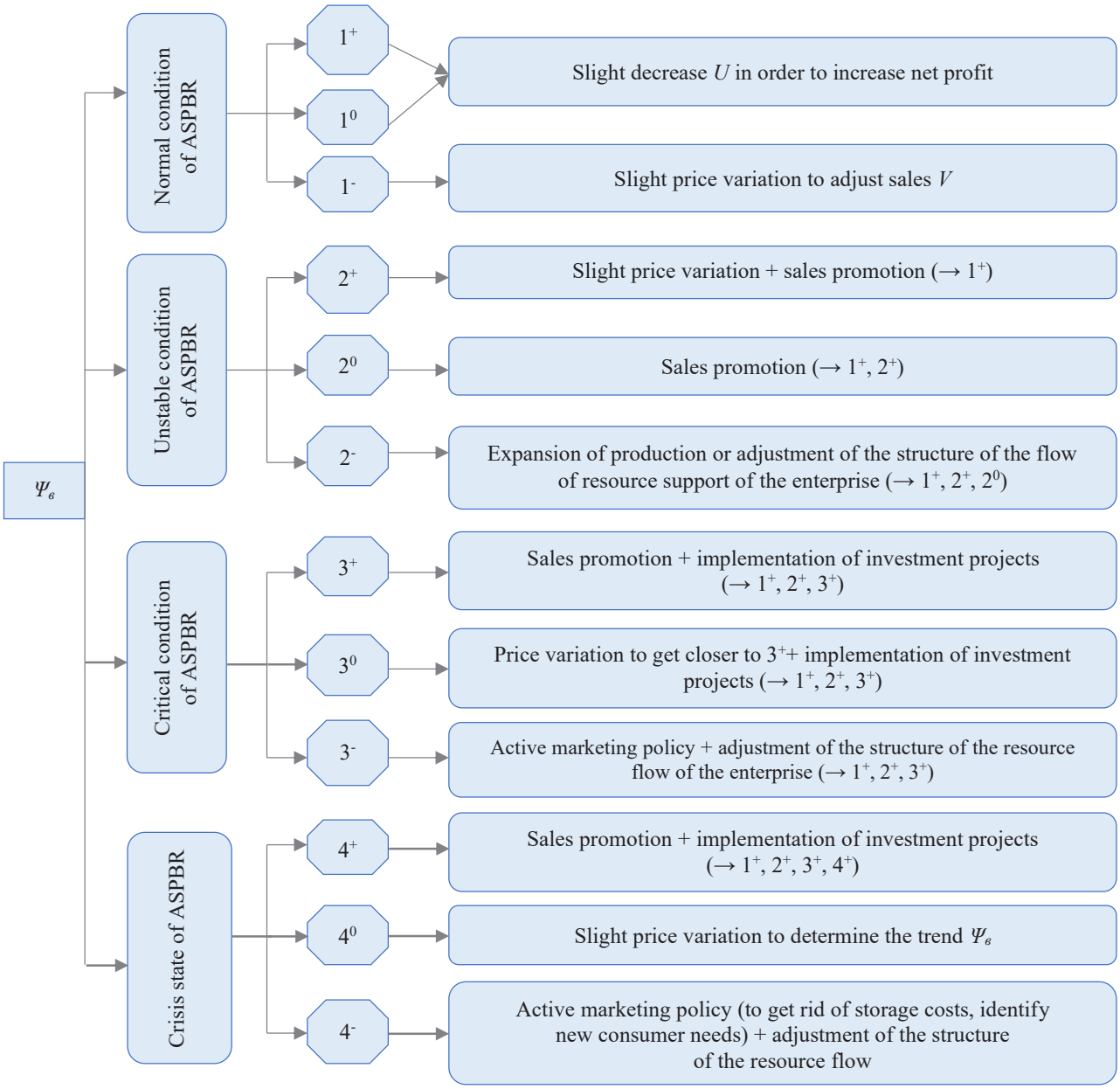


***Figure 4**. Tree of scenarios of the flow of resource support of anti-crisis stability of the potential of break-even development of the agribusiness enterprise*

***Source**: developed by the authors*

To establish a quantitative characterization of the relationship between a balanced structure of assets and sources of funding, it is necessary to determine the optimal (target) parameters of the ASPBR of the agribusiness enterprise. To do this, the current structure of assets is compared with the "ideal" one, and on the basis of certain parameters of the resource flow and its quantitative system component determines the optimal (effective) flow of resources to increase the level of anti-crisis stability of the potential of break-even development of the enterprise and its economic growth in the market.

Thus, the direction to the "ideal" prototype of anti-crisis stability of the potential of break-even development of agribusiness is possible by achieving financial equilibrium, which indicates the efficient use of the resource flow of the entity from its own sources of funding.

We believe that self-financing cannot be reduced only to the hoarding of profits, because the deep foundations of understanding the essence of self-financing, its open and hidden forms can be obtained only in the context of capital movements in a simple and expanded reproduction. Open and hidden forms of self-financing function in a constant dialectical relationship, i.e. in the form of interaction and the transition from one form to another.

Based on the research, we propose to calculate the level of anti-crisis stability of the potential of break-even development, determining the target parameters of self-financing, according to the formula (1) [38; 39]:

$$I_{ASPBR} = P_{of} + P_{edsf} + P_{pe} + P_{cef} + Pmof_{ln} \quad (1)$$

where, I_{ASPBR} – is an indicator of the level of anti-crisis stability of the break-even potential; P_{of} – target parameters of own funds; P_{edsf} – target parameters of efficiency of distribution of sources of financing, USD.; P_{pe} – target parameters of profitability of the enterprise; P_{cef} – target parameters of capital efficiency; P_{ln} – target parameters of liquidity of the enterprise; P_{mof} – target parameters of maneuverability of own funds.

Thus, we think it reasonable to consider the target parameters of self-financing as factors of direct influence on the level of anti-crisis stability of the potential of break-even development and effective activity of agribusiness enterprises. As a criterion of economic efficiency, which reflects the qualitative essence of anti-crisis stability of the potential is the maximum result (effect) at a certain level of costs, or as an equivalent – the minimization of costs for a certain result. At the same time, the level of anti-crisis stability of the potential embodies the range of limits of the target parameters of efficient use of enterprise resources: break-even – the initial level required for the transition to a qualitatively new state of effective activity – self-financing.

RESULTS AND DISCUSSION

In the process of transformational changes in Ukraine, most agribusiness enterprises occur in a critical situation due to the imperfection of the system of organizational, economic and financial-credit mechanisms of management. Depending on the available resources, some agricultural enterprises have different conditions of production. This process involves influencing the anti-crisis stability of the enterprise development potential by forming factors that should have the following types of decomposition: 1) functional decomposition (taking into account the functions of the components of the anti-crisis potential of the enterprise development); 2) decomposition by life cycle (stages of movement of input and output flows of resource support are taken into account); 3) decomposition by physical process (description of the behavior of the stability of the potential of break-even development as a physical process), which in economic processes is analogous to decomposition by life cycle [40].

In addition, the process of anti-crisis stability of the potential of break-even development of agribusiness enterprises can be considered as a production cycle that characterizes the formation of performance indicators (profit, profitability) due to the circulation of value. From this point of view, this process can be represented as a process of transformation of resources into products, which have a certain set of advantages. At the same time, the decomposition of the functional features of the components of anti-crisis stability of the potential allows to systematize the advantages of the products, which are formed at the stages of resource support, production and sales. The authors used multidimensional methods, in particular, the methods of principal components and taxonomic analysis, which involve the calculation of a generalized taxonomy coefficient, which is identified with the factor load of qualitative target parameters of direct impact on the stability potential of break-even development. The first stage of the assessment involves the consolidation of a set of factors in the areas of resource support, production, sales, by the method of the main components. Factors indirectly influencing the potential for break-even development include [18]:

1) factors in the field of resource support: x_1 – employment, pers. per 100 hectares; x_2 – the number of tractors per 100 hectares of arable land (as a modified analogue of the capital stock), units; x_3 – energy supply (energy capacity per 100 ha of agricultural land), kW/ha; x_4 – energy equipment (energy capacity per 1 average annual employee), kW/person;

2) factors of the sphere of production: x_5 – the amount of costs per 1 ha of agricultural land, thousand USD; x_6 – grain and legume yields (as crops for which more than 55% sown area of Ukraine) was allocated in 2020), c/ha; x_7 – average annual milk yield per 1 cow, kg; x_8 – average daily gain of cattle on pasture, fattening, cultivation, gram; x_9 – the level of labor productivity, thousand USD;

3) factors of sales: x_{10} – the level of profitability of sales, %; x_{11} – mass of profit per 1 ha of agricultural land, thousand USD; x_{12} – mass of profit per average annual 1 employee, USD; x_{13} – the level of profitability of agricultural activity, %.

The study of assessing the state of resource support of anti-crisis stability of the potential of break-even development of agribusiness enterprises (within their territorial location in the regions of Ukraine) determines the impact of factors directly affecting its level, taking into account soil and climatic conditions.

In the second stage of application of the principal components method, the actual values of the selected indicators of factor load, which are standardized by the formula, are determined [15]:

$$z_{ij} = \frac{x_{ij} - \overline{x}_j}{\sigma_j} \quad (2)$$

where, z_{ij} – standardized value of the j-th indicator for the i-th enterprise in the region; $\overline{x}_j$ – the average value of the j-th indicator; σ_j – standard deviation of the j-th indicator.

The condition for the application of the principal components method is the existence of a close correlation between the factors of anti-crisis stability of the break-even potential. Therefore, the next stage is the construction of three correlation matrices for standardized values, calculated for three areas of the economic process of enterprises on average per region of the Steppe zone of Ukraine. According to the results of correlation analysis, it was found that there is a close correlation between a number of indicators (the values of some

coefficients exceed 0.8). This testifies to the validity of the assessment of the state of resource support of anti-crisis stability of the potential of break-even development by the method of main components. Thus, in 2013, within the sphere of resource support, the contribution of the first component to the variation of the selected four factors (x_1-x_4) is 65.7%, the second component – 29.3%. In the subsequent assessment, the first component was used, as its anti-crisis factor loads are significantly higher than the load of the second component (Table 1) [41].

For marketing, the first main component describes 94.9% variances. For the following years, the first component was used in the same way for all spheres. In 2017, for resource support, it explains 67.6% of the general variation; for production – 57.8%; for sale – 91.3% variations of the total variance. In 2018, in the field of resource support, the main component was described, which describes 64.8% variations; in production – a component that characterizes 58.5% random fluctuations of the total variance; in implementation – a component that reflects 95.5% variations in the factors of anti-crisis stability of the potential of break-even development. The same applies to 2019, when the first component of the supply sector describes 56.3% variations in variance, production – 49.8%, sales – 92.2%. In 2020, in terms of supply, the first component is determined 55.8% variations in variance, production – 57%, and sales – 93.4%.

Thus, based on the obtained anti-crisis factor loads and shares of total variances in all areas of the reproduction process of anti-crisis stability of the break-even potential of agribusiness enterprises on average per region of the Steppe zone of Ukraine, it can be argued that the values of the first principal components should be used for qualitative and quantitative target parameters. To calculate them, it is necessary to construct equations that formalize the dependence of the stability of the break-even potential on its factors. In generalized form, the formula of the latent index has the form [6]:

$$k = a_1 z_{1+a_2 z_2+\ldots+a_j z_j+\ldots+a_n z_n} \quad (3)$$

where, k – the main component; a_j – anti-crisis factor load for the j-th factor; z_j – standardized value of the j-th factor.

Table 1. *Dynamics of anti-crisis factor load on the stability of the potential of break-even development of agribusiness enterprises on average per region of the Steppe zone of Ukraine in 2013-2020*

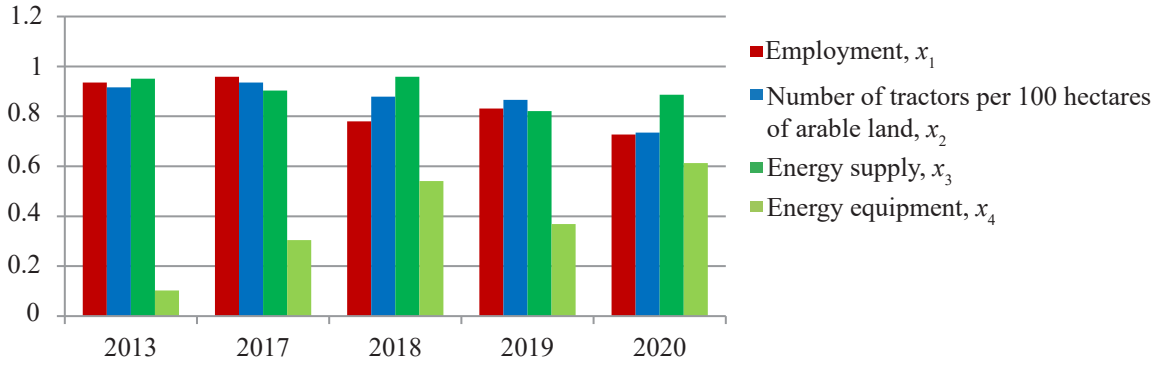
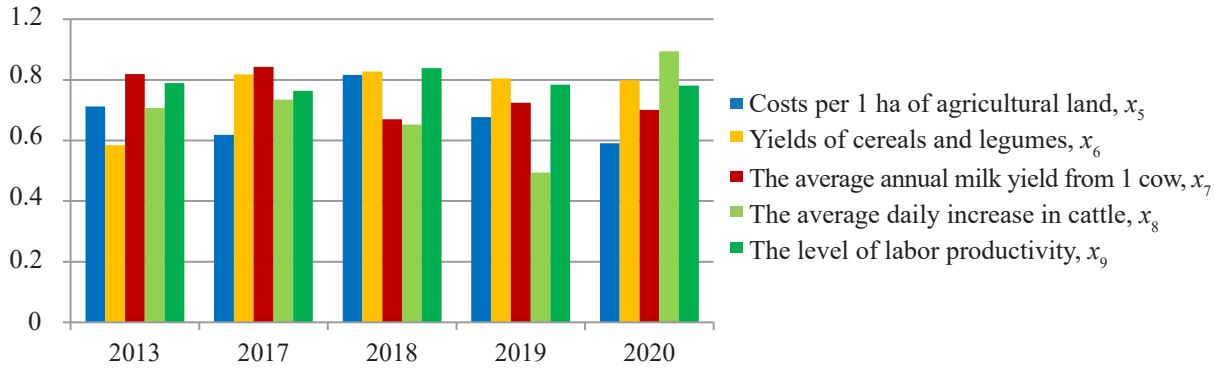
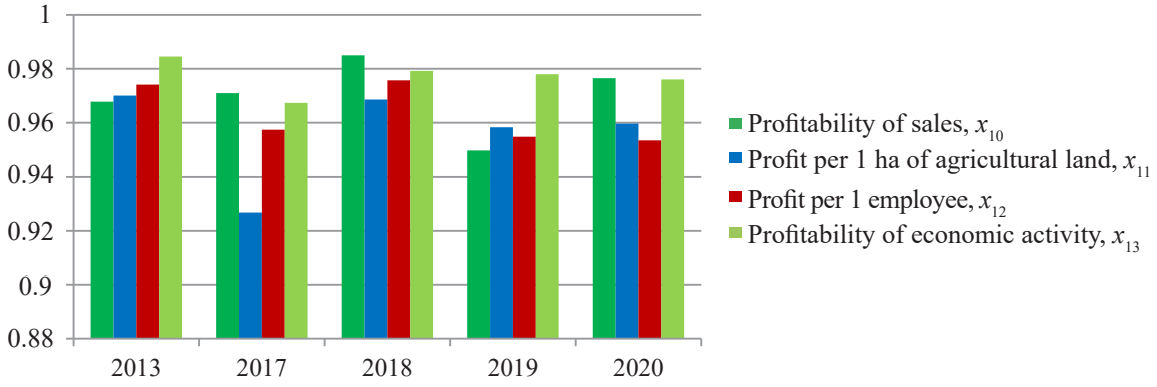
Indicators	2013	2017	2018	2019	2020
Sphere of resource support					
					
Total variance	2.6283	2.7048	2.5914	2.2520	2.2312
The proportion of total variance	0.6571	0.6762	0.6479	0.5630	0.5578
Sphere of production					
					
Total variance	2.6421	2.8859	2.9270	2.4916	2.8857
The proportion of total variance	0.5284	0.5772	0.5854	0.4983	0.5771

Table 1, Continued

Indicators	2013	2017	2018	2019	2020
Sphere of sales					
					
Total variance	3.7964	3.6540	3.8195	3.6891	3.7366
The proportion of total variance	0.9491	0.9135	0.9549	0.9223	0.9342

***Source**: calculated by the authors according to data [41]*

To move from the standardized values of z_j in equation (3) to the actual values of the factors x_j, the variables z_j should be replaced. Based on formula (2), in the expanded form the transformation equation will look like [6]:

$$k = \left[\frac{a_1 x_1}{\sigma_1} - \frac{a_1 \overline{x}_1}{\sigma_1}\right] + \left[\frac{a_2 x_2}{\sigma_2} - \frac{a_2 \overline{x}_2}{\sigma_2}\right] + \ldots + \left[\frac{a_n x_n}{\sigma_n} - \frac{a_n \overline{x}_n}{\sigma_n}\right] \quad (4)$$

In formula (4) we see that a free member appears in the transformed equation, which is calculated as the total value [6]:

$$\left[-\sum_{j=1}^{n} \frac{a_j \overline{x} j}{\sigma_j} = \frac{a_1 \overline{x}_1}{\sigma_1} - \frac{a_2 \overline{x}_2}{\sigma_2} - \ldots \frac{a_n \overline{x}_n}{\sigma_n}\right] \quad (5)$$

Then, the equation of the principal component, taking into account the actual rather than standardized factors, has the form formulsa (6), [6]:

$$k = -\sum_{j=1}^{n} \frac{a_j \overline{x} j}{\sigma_j} + \frac{a_1 x_1}{\sigma_1} + \frac{a_2 x_2}{\sigma_2} - \ldots \frac{a_n x_n}{\sigma_n} \quad (6)$$

The general state of anti-crisis stability of the potential of break-even development of agribusiness enterprises in one region of the Steppe zone of Ukraine by its territorial location is presented in a combination of areas of resource support, production and sales of reduction (Table 2) [41]. Agricultural producers with the best rating assessments of anti-crisis stability of the break-even potential are characterized by high productivity of farm animals (correlation coefficient for meat cattle breeding was – 0.88, for dairy cattle breeding – (-0.67)) and by the level of grain and legume yields (the correlation coefficient is equal to – 0.80), (Table 3) [41].

***Table 2**. The level of stability of the break-even development potential within the crisis factor load and territorial location of agribusiness enterprises on average per one region of Ukraine, 2013-2020*

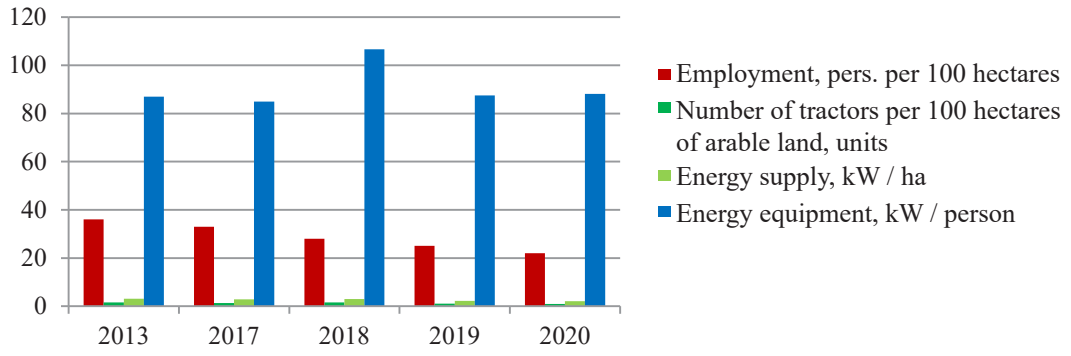
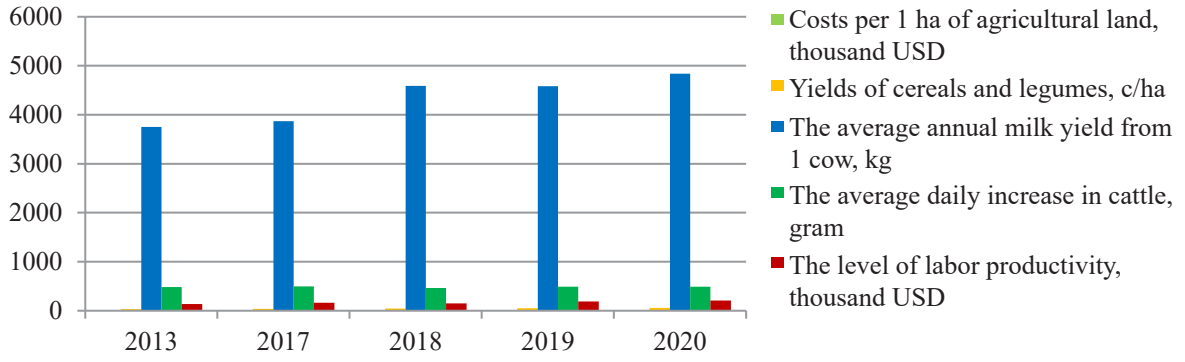
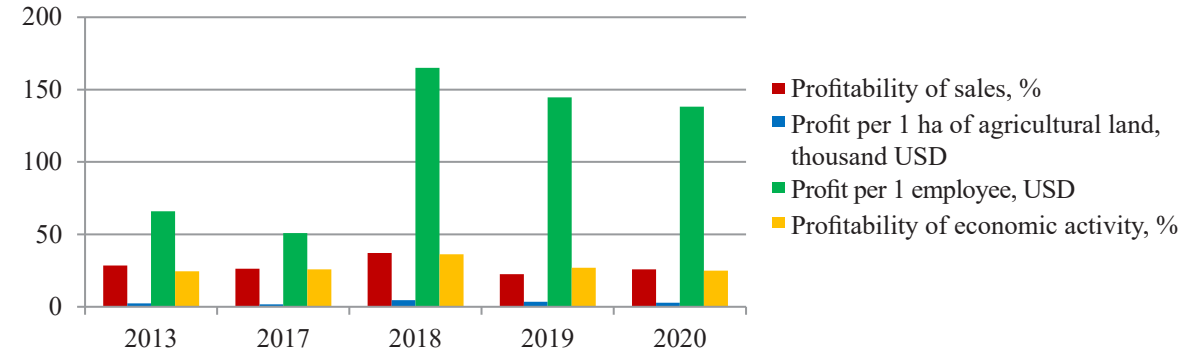
Anti-crisis factor load	2013	2017	2018	2019	2020
Sphere of resource support					
					
Average level of anti-crisis stability of the potential of break-even development in the field of resource support	3	4	3	3	3

Table 2, Continued

Anti-crisis factor load	2013	2017	2018	2019	2020
Sphere of production					
					
Anti-crisis factor load, Average level of anti-crisis stability of the potential of break-even development in the sphere of production	11	9	8	8	8
Sphere of sales					
					
Anti-crisis factor load, Average level of anti-crisis stability of the potential of break-even development in the sphere of sales	11	12	8	8	12

***Source**: calculated by the authors according to data [41]*

***Table 3**. The influence of the factors of production sphere on the assessment of anti-crisis stability of the potential of break-even development on the territorial location of agribusiness enterprises in one region of the Steppe zone of Ukraine*

Indicator	Group of enterprises by rating			Deviation between extreme groups, %	Correlation coefficient of the indicator and rating
	I – to 9	II – 10-16	III – above 17		
Yield of grains and legumes, c / ha	56.0	43.2	35.7	-36.2	-0.80
The average annual milk yield per 1 cow, kg	5306	5074	3644	-31.32	-0.68
Average daily gain of cattle, g	545	513	446	-18.23	-0.88
Costs per 1 ha of agricultural land, thousand USD	9.0	7.0	4.9	-45.24	-0.66
Level of labor productivity, thousand USD	251.7	241.2	180.5	-28.29	-0.59

***Source**: calculated by the authors according to data [41]*

Based on the results of correlation analysis, it was determined that the higher the values of performance indicators of enterprises, the higher the rating of anti-crisis stability of the potential of break-even development in the field of sales (Table 4).

***Table 4**. The influence of sales factors on the assessment of anti-crisis stability of the potential of break-even development on the territorial location of agribusiness enterprises in one region of the Steppe zone of Ukraine*

Indicator	Group of enterprises by rating			Deviation between extreme groups, %	Correlation coefficient of the indicator and rating
	I – to 9	II – 10-16	III – above 17		
Profitability of sales, %	56.0	43.2	35.7	-36.2	-0.80
Profit per 1 ha of agricultural land, thousand USD	5306	5074	3644	-31.32	-0.68
Profit per 1 average annual employee, USD	545	513	446	-18.23	-0.88
Profitability of economic activity, %	9.0	7.0	4.9	-45.24	-0.66

***Source**: calculated by the authors according to data [41]*

The generalized coefficient of taxonomy is calculated, which is defined as the integral level of anti-crisis stability of the break-even potential of the enterprise by factors of direct influence. The taxonomic distances from data points to the upper pole (with the coordinates of the standards) are calculated by formulas (7-8), [14]:

$$c_{ij} = z_{ij} - z_{j0}, d_i = \sqrt{\sum_{j=1}^{n} c_{ij}^2} \quad (7)$$

where, c_{ij} – taxonomic distance of the standardized value of the j-th indicator from the standard for the i-th enterprise in one region of the Steppe zone of Ukraine; d_i – distance from data points to the upper pole for the i-th object; z_{ij} – standardized value of the j-th indicator for the i-th enterprise in one region of the Steppe zone of Ukraine; z_{j0} – reference value of the j-th indicator; n – the number of direct indicators-factors influencing the crisis stability of the break-even potential.

The higher the absolute value of the rating, the less stable the state of the break-even potential of development of the enterprise is. Therefore, for each sphere of influence the standard corresponds to the minimum among all set of a rating (that is 1 place on a rating). After that, the calculation of the taxonomic indicator of anti-crisis stability of the break-even potential is made, which reflects the degree of similarity of the enterprise with the standard formula (8), [21]:

$$\mu_i = 1 - \frac{d_i}{\overline{d} + 2S} \quad (8)$$

where, μ_i – indicator of anti-crisis stability of break-even development potential (taxonomy coefficient) for the i-th enterprise in one region of the Steppe zone of Ukraine; $\overline{d}$ – arithmetic mean distance from the reference object, determined by the formula: $\overline{d} = \frac{1}{m}\sum_{i=1}^{m} d_i$, where, m – the number of surveyed enterprises; S – standard deviation of distances from the reference object, determined by the formula: $S = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(d_i - \overline{d})^2}$.

The results of the assessment give grounds to assert that the enterprises of Kherson and Zaporizhzhia regions of the Steppe zone of Ukraine had the most stable anti-crisis state of the potential of break-even development in 2013-2020. The position of the producers of Mykolayiv region significantly worsened, from 7 place in the rating in 2013 they gradually decreased to 23 place in 2020. First, this is due to the deterioration of indicators-factors of sales. Stable positions of leaders of agricultural producers are not typical for any of the regions. Estimates of resource support of the anti-crisis state of the potential of break-even development by factors of direct impact are the most successful for agribusiness enterprises in Zaporizhzhia region of the Steppe zone of Ukraine. To do this, we have identified the factors that have the most significant impact on the effective functioning of economic entities in the area (Table 5) [41].

***Table 5**. Assessment of resource support of the anti-crisis state of the potential of break-even development of agribusiness enterprises in Zaporizhzhia region of the Steppe zone of Ukraine by indicators of direct impact*

Factors of indirect influence	The coefficient of pair wise correlation between the quantitative assessment of the factor and the level of anti-crisis stability of the break-even potential					On average for 2013-2020
	2013	2017	2018	2019	2020	
Employment	0.39	0.28	0.30	0.44	0.49	0.38
Number of tractors per 100 hectares of arable land	0.02	0.17	0.11	0.18	0.43	0.18
Energy supply	0.20	0.18	0.24	0.37	0.31	0.26
Energy equipment	0.02	0.26	0.11	0.13	0.19	0.14

Table 5, Continued

Factors of indirect influence	The coefficient of pair wise correlation between the quantitative assessment of the factor and the level of anti-crisis stability of the break-even potential					On average for 2013-2020
	2013	2017	2018	2019	2020	
Costs per 1 ha of agricultural land	0.53	0.72	0.84	0.33	0.83	0.65
Yields of cereals and legumes	0.27	0.76	0.68	0.32	0.61	0.53
Average annual milk yield	0.54	0.72	0.43	0.54	0.54	0.55
Average daily gain of cattle	0.42	0.56	0.37	0.04	0.50	0.38
Level of labor productivity	0.07	0.61	0.72	0.51	0.67	0.52
Profitability of sales	0.66	0.58	0.80	0.65	0.83	0.70
Profit per 1 ha of agricultural land	0.86	0.88	0.80	0.56	0.90	0.80
per 1 average annual employee	0.61	0.64	0.78	0.61	0.81	0.69
Profitability of economic activity	0.85	0.55	0.79	0.63	0.94	0.69

***Source**: calculated by the authors according to data [41]*

Authors used cluster analysis, the purpose of which is to select the object with its subsequent organization into relatively homogeneous groups of agribusiness enterprises by the share of individual elements of the qualitative system-resource component of anti-crisis stability of the potential of break-even development in their total volume. This makes it possible to distinguish five types of economic entities in the regions of the Steppe zone of Ukraine with different structure of current assets (Table 6) [41].

***Table 6**. The results of cluster analysis of agribusiness enterprises in the regions of the Steppe zone of Ukraine on average for 2016-2020*

Indicator	Groups of clusters					On average, in total
	1	2	3	4	5	
Number of enterprises	7	9	4	5	4	29
The share of current assets in the production cycle to the total value of current assets, %	80.9	77.3	46.3	84.3	39.9	65.7
– Production inventory	44.9	30.1	16.4	32.3	18.4	28.4
– Animals for breeding and fattening	2.6	3.0	1.1	1.9	0.9	6.6
– Unfinished production	33.2	44.1	28.7	48.9	20.6	35.1
– Future expenses	0.2	0.1	0.1	0.2	0.1	0.1
Share of current assets in the financial cycle to the total value of current assets, %	18.9	22.4	53.5	15.4	59.9	34.0
– Finished product	4.2	5.8	35,5	3.9	7.2	11.3
– Funds in calculations	13.9	10.0	12.1	10.9	51.8	19.7
– Cash	0.8	6.6	5.9	0.6	0.9	3.0
Other current assets	0.2	0.5	0.2	0.3	0.2	0.3
Material consumption	0.89	0.63	0.97	0.68	0.98	0.8
Duration of turnover of current assets, days	363	341	297	302	389	338
Profitability of self-financing of current assets, %	4.9	24.4	35.3	3.6	-2.9	13.1

***Source**: calculated by the authors according to data [41]*

It is worth noting that in agribusiness enterprises of the third and fifth clusters, in which with a similar structure of current assets in the production cycle and a significant share (over 50%) of current assets in the financial cycle, there are different indicators of their efficiency. The reason for this trend is the excessive diversion of funds into receivables in the group of enterprises of the fifth cluster, where its size is 51.8% of the overall structure of current assets. In the general structure of current assets of the third and fifth clusters, the share of current assets in the financial cycle to their total value is 53.5% and 59.9% respectively. This led to an increase in the duration of their turnover (for the group of enterprises of the third cluster it is 297 days, for the group of the sixth cluster – 389 days). The enterprises of the first, second and fourth clusters are characterized by a significant share of inventories, unfinished production (especially for the fourth cluster) and funds in the calculations (for the first cluster). In addition, in the enterprises of the first two clusters animals for breeding and fattening occupy a significant share in the structure of current assets. We should note that the enterprises of the Steppe zone of Ukraine with an average share of cash in the structure of current assets (second, third clusters), the profitability of their self-financing is significantly higher and is 24.4% and 35.3% respectively.

Thus, at the agribusiness enterprises of Zaporizhzhia region of the Steppe zone, as the profitability of self-financing of current assets increases, their share in the production cycle decreases. This is mainly due to a decrease in the share of unfinished production in the structure of current assets. At the same time, the increase in the profitability of self-financing of current assets is accompanied by an increase in the share of finished products and, especially, cash (Table 7) [41].

According to the principles of reliability, rationality of resource support, controllability and synergy, the quantitative component of anti-crisis stability of break-even potential is determined by the redistribution of sources of financing current assets, taking into account the synchronicity and rhythm of cash flows allowing to achieve the main purpose of its components – ensuring the stabilization of functioning and the formation of economic growth of agribusiness enterprises in the Steppe zone in the long run.

***Table 7**. The structure of current assets of agribusiness enterprises in Zaporizhzhia region of the Steppe zone of Ukraine by the level of profitability of self-financing of current assets, on average for 2016-2020*

Indicator	Groups of enterprises on the profitability of self-financing of current assets					On average, in total
	Unprofitable above – 13.1	Unprofitable from 13.1 to 0	Profitable			
			From 0.1 to 10.0	From 10.1 to 30.0	Above 30.1	
Number of enterprises	2	2	4	12	9	29
Profitability level, %	-21.4	-7.8	6.1	28.1	36.2	8.3
The share of current assets in the production cycle, total, %	67.1	68.2	67.7	61.8	63.3	65.6
– Production inventory	15.4	19.7	31.6	32.3	39.9	27.6
– Animals for breeding and fattening	2.4	3.1	1.9	2.3	2.0	2.5
– Unfinished production	49.4	45.8	34.1	27.0	21.3	35.5
– Future expenses	0.2	0.1	0.1	0.2	0.1	0.1
Share of current assets in the financial cycle, total, %	32.6	31.6	31.7	38.1	36.3	34.1
– Finished product	2.9	3.7	9.4	19.2	16.8	10.4
– Funds in calculations	29.5	27.4	18.9	10.2	11.4	19.5
– Cash	0.2	0.5	3.4	8.7	8.1	4.2
Other current assets, %	0.3	0.2	0.6	0.1	0.4	0.3

***Source**: calculated by the authors according to data [41]*

Quantitative system-resource component of break-even development potential is assessed by qualitative or conditionally qualitative indicators and characterizes the degree of meeting the need for financing current assets by a set of own and borrowed resources, represented by the following indicators [42; 43]:

– indicators that reflect compliance (non-compliance) with the target parameters: the coefficient of synchronicity of incoming and outgoing cash flows by volume (x_1); the coefficient of rhythmicity of incoming and outgoing cash flows in terms (x_2); coefficient of uniformity of cash receipts during the period (x_3); coefficient of uniformity of cash payments during the period (x_4); the coefficient of synchronicity of incoming and outgoing cash flows during the period (x_5); coefficient of balance of receivables and payables by volume (x_6); coefficient of balance of receivables and payables by terms (x_7); the ratio of total income and total costs of the enterprise (x_8); the coefficient of conformity of the formed reserve of resources at the enterprise (x_9);

– dynamic indicators that reflect the change of target parameters in space and time: capital growth rates (x_{10}); equity growth rates (x_{11}); growth rates of current liabilities and collateral (x_{12}); growth rates of long-term liabilities and collateral (x_{13}); growth rates of accounts payable (x_{14}); net profit growth rates (x_{15}); gross profit growth rates (x_{16}); growth rates of financial result from operating activities (x_{17}); growth rates of pre-tax financial result (x_{18}).

To establish the priority of the choice of indicators for assessing the system-resource component of the anti-crisis stability of the potential of break-even development, using the expert method, a forecast assessment of the quality of resource support of the structure of current assets is carried out. The reliability of the assessment ensures the representativeness of the results with probability 95%. Thus, according to the calculations, the relative importance of the indicators, which corresponds to the percentage of variance, is for the indicators $x_{10}, x_{15}, x_1, x_8, x_7$ – 28.6%, 23.8%, 17.4%, 13.8%, 7.8% respectively. These values correspond to the weights in the integrated model of resource support for the quantitative component of anti-crisis stability of the break-even potential of agribusiness enterprises of the Steppe zone, which forms the structure of the qualitative component (current assets) and has the form:

$$I_{rs}^{ASPBR} = 0.286 \times x_{10} + 0.238 \times x_{15} + 0.174 \times x_1'' + 0.138 \times x_8 + 0.078 \times x_7 + \varepsilon \quad (9)$$

where, I_{rs}^{ASPBR} – an integrated indicator of resource support for the quantitative component of anti-crisis stability of the potential of break-even development of agribusiness enterprises; x_{10} – capital growth rates; x_{15} – growth rates of net profit; x_1 – the coefficient of synchronicity of incoming and outgoing cash flows by volume (the ratio of incoming cash flows to outgoing for the period); x_1'' – modified value of the indicator x_1; x_7 – coefficient of balance of receivables and payables by terms (calculated as the correlation coefficient between these indicators for the period with quarterly detailing); ε – the probability of error due to the influence of unaccounted factors. All indicators of the model are index values that have the same dimension and do not require standardization. The optimal value for the indicator x_1 is 1. Deviation from it indicates a decrease in the quality of resource support in terms of the quantitative component of anti-crisis stability of break-even potential: x_1>1 indicates an excess of incoming cash flow over outgoing and is a sign of inefficient use of funds as a result of their accumulation; x_1<1 indicates an excess of outgoing cash flow over incoming, which leads to the accumulation of debt and reduced solvency. In view of the above, model (9) uses a modified value of the indicator x_1, which takes into account the negative impact of values of indicators other than 1, by reducing the integrated indicator. The modified value of the indicator x_1 is proposed to be determined by formula (10) [23]:

$$x_1'' = \begin{cases} x, when\ x_1 \leq 1 \\ \dfrac{1}{x_1}, when\ x_1 \geq 1 \end{cases} \quad (10)$$

For the indicator of the balance of receivables and payables in terms of x_7 the optimal value is also 1. If $x_7 \neq 1$, then there is an imbalance of receivables and payables in time, which leads to a violation of the solvency of the enterprise. This indicator is estimated by the correlation coefficient at the value of [-1;+1]. Under condition $x_7 \neq 1$ there is a decrease in the integrated indicator, respectively, the greater the deviation from 1, the greater the decrease in the indicator I_{rs}^{ASPBP}.

The levels of the quality of resource support on a quantitative component of anti-crisis stability of potential of break-even development of the enterprises of agribusiness are defined on the basis of values of the integrated indicator formula (9) by Fibonacci rule formula (11) [23]:

$$\begin{cases} I_{rs_1}^{ASPBP} = I \\ I_{rs_2}^{ASPBP} = I_{rs_{min}}^{ASPBP} {}^{ASPBP}_{rs_{max}}{}^{ASPBP}_{rs_{min}} \\ rs_{max}{}_{ASPBP}{}^{ASPSP}_{rs_{min}} \\ rs_{min}{}_{ASPBP} \end{cases} \quad (11)$$

where, $I_{rs_{min}}^{ASPBP}$ – the minimum possible value of the integrated indicator; $I_{rs_{max}}^{ASPBP}$ – the maximum possible value of the integrated indicator; [$I1_{min}$ – allow level of quality of resource provision in terms of the quantitative component of anti-crisis stability of the potential of break-even development of agribusiness enterprises; $I_{rs_{min}}^{ASPBP}{}^{ASPBP}_{rs_2}$ – the average level of quality of resource support in terms of the quantitative component of anti-crisis stability of break-even development potential; ($I_{rs_2}^{ASPBP}$, $I_{rs_{max}}^{ASPBP}$) – high level of quality of resource provision on the quantitative

component of anti-crisis stability of the potential of break-even development.

The calculated integrated indicator does not have a lower and upper measurement limit. The lower limit is taken as 0, in the absence of anti-crisis measures for the stability of the potential of break-even development of the enterprise (all indicators are equal 0); the upper limit (all coefficients are equal 1), formed according to the Main Department of Statistics of Ukraine (growth rates of resources (capital and net profit), balance of cash flows, receivables and payables, income and expenses) [44]. Thus, the average capital growth rate in 2020 in Ukraine was 1,006; average growth rate of net profit – 0.66 [35]. According to the value 0.8 is the level of the integrated indicator in the range: low – [0; 0.3], medium – [0.3; 0.5], high – [0.5; 0.8]. However, taking into account all possible variants of the integrated indicator, the low level of quality of resource support in terms of the quantitative component of anti-crisis stability of the break-even potential is determined at $I_{rs}^{ASPBP} \leq 0.3$, high – $I_{rs}^{ASPBP} \geq 0.5$.

Within the framework of researches for forecast representativeness of assessment of the level of quality of resource support by quantitative component of anti-crisis stability of break-even development potential on average per one enterprise of the Steppe zone region and by Steppe zone regions as a whole the growth rates of capital, net profit, income and expense ratio are calculated, which are presented in (Fig. 5-6).

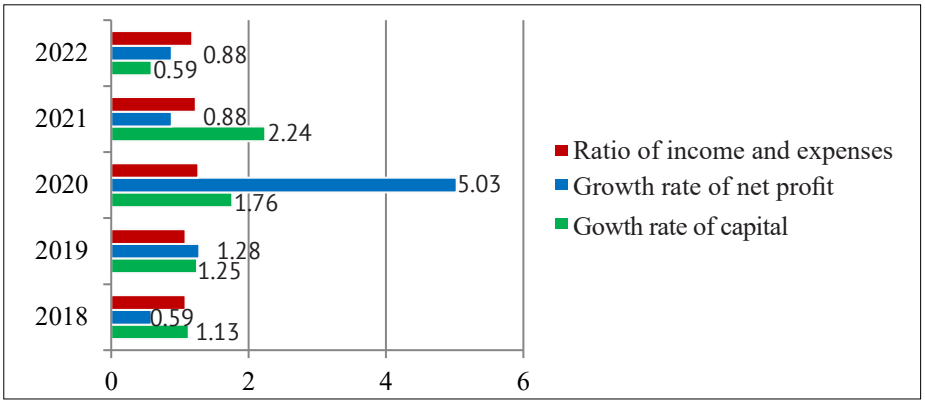


***Figure 5**. Forecast level of resource support by the quantitative component of anti-crisis stability of the break-even development potential on average in Zaporizhzhia region of the Steppe zone of Ukraine, 2021-2023*

***Source**: calculated by the authors*

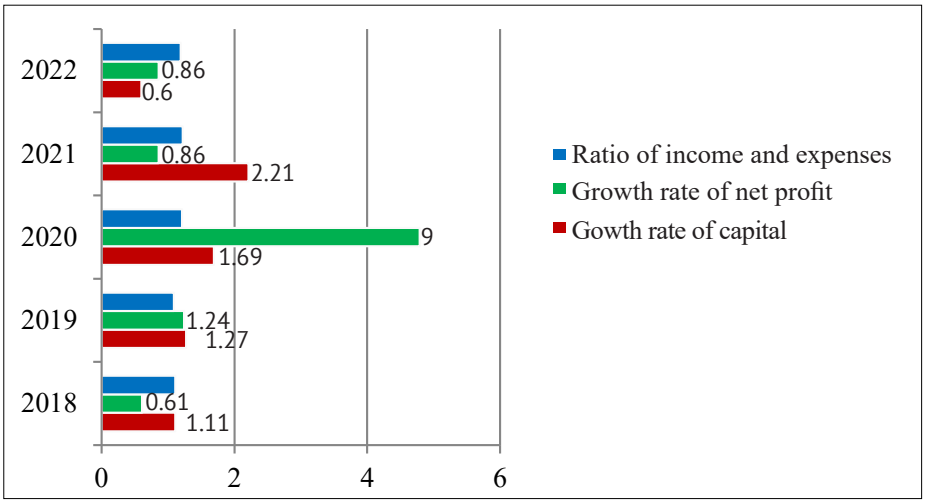


***Figure 6**. Forecast level of resource support by the quantitative component of anti-crisis stability of the potential of break-even development on average per one agribusiness enterprise of Zaporizhzhia region of the Steppe zone of Ukraine, 2021-2023*

***Source**: calculated by the authors*

Thus, the deviation of the average indicators per enterprise of Zaporizhzhia region of the Steppe zone, from the average level in the region as a whole, does not exceed |5%|, which with probability 95% allows asserting the reliability of the calculation results. It is important to emphasize that the structure of the resource component of self-financing of agribusiness enterprises is dominated by equity, the factor of change of which is the financial result, and its value is the most effective source of anti-crisis stability of break-even development

potential. In this connection the further task of our study is to forecast the target parameters of self-financing to determine the optimal level of stabilization of economic growth of economic entities of the Steppe zone. The grouped target parameters are formed into one factor, which characterizes the reproductive aspect of self-financing of anti-crisis stability of the potential of break-even development.

Accordingly, a representative integrated level of stability of break-even development potential by self-financing target parameters is determined by the "center of gravity" method based on minimizing the sum of Euclidean distances, which allows to determine indicators in the middle of the factor and maximize them between groups [45]:

$$d_{ij} = \sqrt{\sum_{k=1}^{n}(x_{ik} - x_{jk})^2} \qquad (12)$$

where, d_{ij} – Euclidean distance between objects (indicators) i and j; x_{ik} – the value of the i-th indicator for the k-th agribusiness enterprise in the region; n – number of enterprises in the region (n=32).

Based on the forecast, it is determined that the system of factors-representatives of anti-crisis stability of the potential of break-even development of agribusiness enterprises in Zaporizhzhia region of the Steppe zone of Ukraine consists of: coefficient of autonomy (own funds factor), asset turnover ratio (profitability factor of the enterprise), the rate of return on equity (factor of capital efficiency), the ratio of absolute liquidity (liquidity factor of the enterprise), the coefficient of maneuverability of working capital (the factor of maneuverability of own funds). According to the results of the forecast for 2021-2023, agribusiness enterprises in Zaporizhzhia region of the Steppe Zone are divided into 4 clusters according to the levels of the range of limits of influence of target parameters of self-financing on the level of anti-crisis stability of break-even development potential. Since the degree of similarity between all clusters is zero, it means that the ranges of values of indicators attributed to different levels do not intersect and the levels of values of indicators are formed on the basis of actual values of indicators for enterprises included in the cluster.

The ranges of the limits of the impact of target parameters of self-financing on the level of anti-crisis stability of the potential of break-even development of agribusiness enterprises of Zaporizhzhia region of the Steppe zone are presented in (Fig. 7).

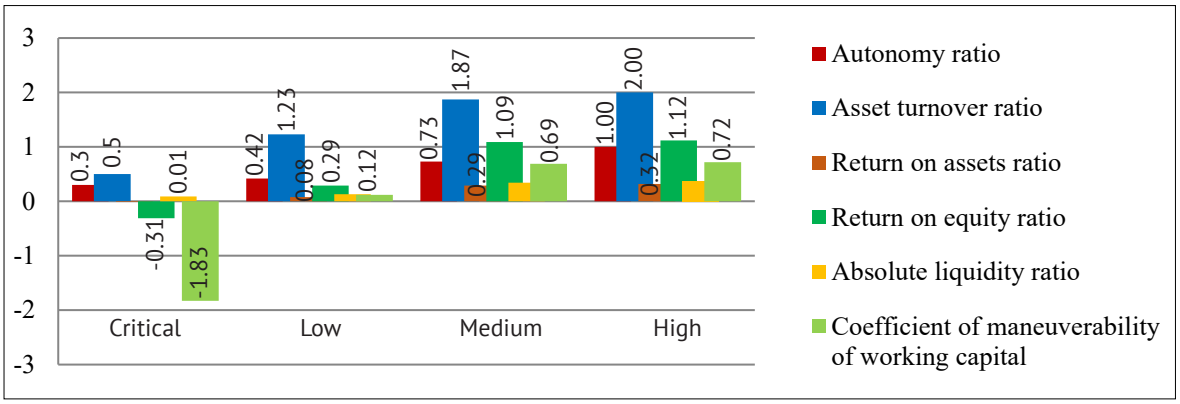


***Figure 7**. Forecast range of limits of target parameters of self-financing and their influence on the level of anti-crisis stability of the potential of break-even development of agribusiness enterprises in Zaporizhzhia region of the Steppe zone for 2021-2023*

***Source**: calculated by the authors*

Thus, the forecast level of the range of limits of the target parameters of self-financing, which provides the overall integrated level of anti-crisis stability of the break-even development potential, according to the selected indicators is sufficient. Because self-financing is characterized by the availability of sufficient equity to cover current liabilities, financial independence and the availability of self-sustaining sources of break-even development, all target parameters of self-financing are high.

CONCLUSIONS

Thus, the attributes of strategic priorities to increase the anti-crisis stability of the potential of break-even development of agribusiness enterprises should be based on the principles of competitive advantage and target parameters of self-financing in the context of their equivalent relations with other entities in their territory (i.e., in the domestic and foreign markets of raw materials and food), on the program-targeted approach to the reproduction of stable economic growth in the choice of effective tools for regulating the resource support of agricultural producers. Only on the basis of organic combination and complementarity of internal and external stabilization programs to reproduce self-financing and quality level of resource support or regulation of profits of agricultural producers it is possible to use methods of subsidizing, dating, stimulating resource-saving technologies, placing funds in startup projects of economic growth of enterprises, in conditions of cyclical downturns of break-even development. This requires identifying areas

for balancing the production and financial cycle, the accumulation of a significant amount of own resources through additional capitalized reserves, cash flow management with limited involvement of external resources. These areas can be addressed through the introduction of stabilization anti-crisis programs that take into account the stimulating levers of strategic priorities of resource support, which are necessary regulators of the reproductive mechanism to ensure anti-crisis stability of break-even development potential.

In this case, the variability of resource support through the flow of resources of economic entities should cover all possible changes in the structure of financing. First, each progressive movement of the flow of resources in the cycle of the reproduction process of the production and financial cycle causes changes in both the target parameters of self-financing and qualitative sources of resource support. Second, the total amount of funding changes when the flow of resources provides a regrouping of the structure of property assets. That is, this variability in operations is determined by the need to finance variable costs and costs associated with the replacement of machinery and equipment. Third, the balance between financial resources and their sources must be maintained after any flow of resources. This equality arises when the redistribution of the balances of financial resources, i.e. with an increase or decrease in the level of anti-crisis stability of the potential of break-even development.

When choosing high-quality sources of resources for agricultural enterprises, it is necessary to take into account the specifics of production and the formation of cash flow in the financial cycle. The volume and structure of resource support should be formed on the basis of real opportunities for the development of financial resources, return on investment and ensuring profitable activities in the short and long term. The structure of resource support should be considered as the ratio of the cost of all own resources to the cost of borrowed ones, which are used in the reproductive process of stabilization of anti-crisis stability. It is necessary to understand and take into account these features when synchronizing and accelerating the process of resource inflow and capitalization of their temporarily free balances, carrying out investment operations, taking into account the possible terms of return and risk.

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Антикризова стабільність потенціалу розвитку беззбитковості та його ресурсне забезпечення в агробізнесі

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Анотація. У статті розглядається антикризова стабільність потенціалу беззбиткового розвитку та його ресурсна підтримка в агробізнесі. Доведено необхідність синергетичного підходу до оцінки динамічного потоку ресурсів, здатних генерувати власні джерела фінансування для активації цільових параметрів кризової стабільності потенціалу розвитку беззбитковості та розробки альтернативного сценарію самофінансування виробничо-фінансового. Обґрунтовано відтворювальний процес ресурсного забезпечення антикризової стабільності потенціалу безпечного розвитку підприємств агробізнесу. Представлена модель оцінки цільових параметрів антикризової стабільності потенціалу збиткового розвитку аграрного бізнесу та матриця її точкової оцінки під час вибору альтернативного сценарію самофінансування. Розроблено сценарії потоку ресурсного забезпечення антикризової стабільності потенціалу збиткового розвитку підприємства агробізнесу. Запропоновано показник рівня антикризової стабільності потенціалу беззбитковості розвитку відповідно до визначених цільових параметрів самофінансування. Проаналізовано динаміку навантаження антикризового чинника на стабільність потенціалу розвитку беззбитковості підприємств агробізнесу в середньому в одному регіоні Степової зони України за територіальним розташуванням. Кластерний аналіз використано для оцінки елементів якісної системно-ресурсної складової антикризової стабільності потенціалу розвитку беззбитковості з відокремленням типів підприємств агробізнесу в регіонах Степової зони України з різною структурою активів. Визначено прогнозний рівень ресурсного забезпечення відповідно до кількісної складової антикризової стабільності потенціалу розвитку беззбитковості в середньому за регіонами Степової зони України та на одне підприємство агробізнесу регіону. Представлено діапазон прогнозів меж цільових параметрів самофінансування та їх вплив на рівень антикризової стабільності потенціалу збиткового розвитку підприємств агробізнесу в середньому за одним регіоном Степової зони

Ключові слова: антикризова стабільність, підтримка ресурсів, платоспроможність, рентабельність, самофінансування, беззбитковий розвиток

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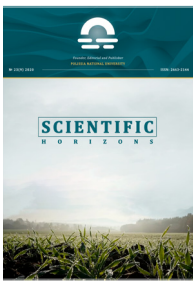

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Inclusive Development of the World Countries under Conditions of Globalisation: Models and Arguments

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Abstract. This study investigates the features of economic growth in different countries of the world, which are described by differences not only in the achieved growth indicators, but also in the trajectory and nature of stimulating this process. The purpose of this study is to assess the impact of existential parameters of the functioning of countries (leading and growing economies) on the inclusivity of their development in the context of economic globalisation, as well as to justify the priority vectors of socio-political and economic changes aimed at realising the growth potential according to the concept of sustainability. The methodological framework of the research comprises methods of descriptive statistics, correlation analysis, and step-by-step regression. The index of development inclusiveness recommended by the World Economic Forum is used as the main indicator of the country's development. The information basis of this study included international databases representing data by country. The results of the study allowed identifying the main factors of economic development and the dependence of economic growth separately in the leading and developing countries of the world. It is proved that despite the direct or indirect impact of these factors on the economic development of the world's leading countries and countries with growing economies, there is no universal model that would ensure economic growth with a focus on sustainable development. However, it is possible to identify a group of factors that ensure the maximum effect of economic growth. Thus, for countries with growing economies, human development is a priority, while for the leading countries of the world, economic growth is mainly driven by factors such as the environmental footprint per person, the Human Development Index, the Globalisation Index and the cost of imported resources. Dynamic changes in the global space, trends towards further development of human capital in all countries, unpredictable consequences of the impact of COVID-19 pandemics determine the prospects for further research in this area

Keywords: globalisation, differentiation, inclusive development, economic growth

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INTRODUCTION

Dynamic and inclusive growth of the global economy plays a key role in achieving the Sustainable Development Goals. However, the response to the risks associated with the 2019 pandemic and recession is typical for all countries of the world, regardless of their level of economic development. And, if in 2017-2018 the economic growth rate in most countries of the world increased and approached the maximum potential values, then in the following years it decreased at a record level in the developed countries of the world. In the post-pandemic period, the economies of these countries started to recover: there is a fairly high load of economic potential in most industries [1].

Choosing a development model in the modern world is a multifaceted process that covers such economic components as innovation, labour productivity, quality of life of the population, environmental and food security, competitiveness, Freedom Index, etc. To maintain their key role and place in the global economy, the developed countries must introduce substantial changes in economic life. For instance, such changes are subject to development strategies (tax growth/reduction, market globalisation), organisation of production processes (modernisation, introduction of high technologies), sociocultural values (targeted social support), which corresponds to the concept of Norbert Thom, known as "Change Management". The package of changes includes organisational, personnel, communication, information, physical, and environmental components. A characteristic postulate of this model is the crisis, which serves as an impetus for changes [2]. The American economist S. Kuznets associates the development of the economic model with the leading role of human capital. In conditions of its insufficiency or poor quality, the country loses its competitiveness and technological mode [3].

The pandemic has shown "blind spots" in the economies of developed countries. These were problems in social protection, structural inequality, environmental degradation, and the climate crisis. Widespread recognition of the ideas of a green economy in industrial countries encourages the development of indicators (natural intensity of GDP, resource intensity, dynamics of emissions, etc.). The green economy is gaining signs of a new model of prosperity and employment solutions. Since 2008, the OECD has been actively promoting the green economy principles in the context of anti-crisis policy, threats of recession, and stimulating investment generation [4]. In the EU Member States, "green measures" are aimed at creating alternative energy sources, developing public transport, building eco-structures, and improving recycling systems [5].

Transformations in the life of society to preserve the environment and develop an environmentally oriented economy are attracting interest in developed countries in such a new model as the "blue economy". The philosophy of the new "blue economy" is to introduce innovative ways to manage and use available resources (coastal areas, ocean and sea energy, fishing and processing, navigation, marine tourism, aquaculture, marine biotechnology, wind energy facilities in water areas) to combat environmental problems and climate change [6]. Innovative and high-tech priorities allow replacing any resource with another that is necessary for production. Therefore, there is no waste in nature, since the by-product is the source of the new product. This enables highly developed countries to implement successful economic, social, and environmental business projects. Thus, highly developed countries modernise their economies towards green technologies and ensure the growth of environmental efficiency of the economy, which constitutes the essence of their modern industrial policy.

Despite numerous attempts to find a growth model of both political and scientific nature, the answer to the question of the impact of individual factors on this process, as well as its results, remains open for different countries of the world. The debate, multi-vector, and multifaceted nature of available theoretical concepts and practical models of economic development, the dynamism, and unpredictability of changes in the global environment permanently sharpen scientific interest in the process under study, as well as motivate new attempts to develop an effective methodology and conduct scientific developments. This paper is no exception, since *the purpose of this study* is to assess the impact of existential parameters of the functioning of countries (leading and growing economies) on the inclusivity of their development in the global economy environment, as well as to justify the priority vectors of socio-political and economic transformation aimed at realising the growth potential according to the concept of sustainability.

THEORETICAL OVERVIEW

Research of economic development conventionally occupies a leading place in the studies of leading researchers and economists and formed the basis for the development of a methodology for understanding evolutionary processes in the global economy system, enabling the design of develop basic theoretical models of growth. Modern economic science is saturated with many alternative theoretical approaches to substantiating models of economic development and growth. The most reasoned and widespread are as follows: the linear growth theory; the structural change theory; the dependence theory; the neoclassical theory; the new growth theory; the property rights theory.

Developed in the 1950s-1960s by the American scientist V. Rostow, *linear growth theory* is based on ensuring economic growth through savings and investments. Followers of this theory have established that each economic system must undergo separate stages of development (traditional society → maturation of conditions

for a breakthrough → breakthrough towards growth → transition to technological maturity → period of mass consumption) [7]. The main emphasis of Rostow's theory is to focus on a new type of economy in developed countries, which is based on a combination of factors of production, savings, and investment that can ensure high rates of economic growth. Despite the advantages of the basic hypothesis of this theory, it had several adverse aspects for Western capitalist countries, including political orientation (through the dominance of US foreign policy) to low-income countries during economic development and promotion of the model of US global influence on industrialisation and urbanisation in such countries [8].

The impact of the economic and energy crisis on the economy of developed countries in the 1970s became the basis for the development of the *structural change theory*, which allowed determining the quantitative criteria for the model of economic development of countries. Some researchers have focused their developments on the fact that the structural transformation of economic systems involves strengthening the role of industry in the structure of the national economy. This strengthening is achieved due to the gradual outflow of excess labour of the agricultural sector in the field of industrial production [9]. Therewith, the theory of structural transformations does not factor in such vital indicators as the technological development of the country and the functioning of the competitive labour market. Under such conditions, the surplus of labour can flow from one industry to another and cause full employment either in the industrial or in the agricultural sector [10], which partially contradicts the concept described by the authors.

The research of R. Prebish [11] served as the basis for the development of the *dependence theory*. The concept of this theory is that interdependence between the countries is the result of the dependence of colonies on metropolises and countries that are economic leaders. The proposed model of economic development of countries is also based on the consequences of non-equivalent exchange in mutual trade procedures. The non-equivalence of exchange lies in the fact that developed countries receive economic and technological rent, while multinational companies exploit the scale-up of production, natural and human resources of less developed countries.

Supporters of *neoclassical theory of economic development* [12], focusing on the deregulation of markets and minimising the influence of the state, argued the need to encourage entrepreneurship and reform labour markets. The postulates of this theory were actively promoted in the activities of international organisations such as the IMF and the World Bank [13]. The basic ideas of this theory turned out to be related to the problem of ensuring sustainable economic growth through a combination of incentive factors (labour, capital, technology). If T. Swan preferred an increase in the number of exogenous populations as a factor of economic growth [14], then R. Solow incorporated a technological variable into the theory [15], there by proving the importance of technology in progressive transformations of the world.

The departure from the ideology of development based on dependence on physical resources has become a qualitative feature of *the new growth theory,* which focuses on the desires and needs of individuals. Knowledge is recognised as a key factor in economic growth, as knowledgeable people buy, sell, and invest wisely and stimulate more substantial economic growth [16]. In addition, knowledge is considered as an intangible asset with the potential for exponential growth, and therefore the target of government efforts and programmes should be human development, the education system, research, and investment that will bring new knowledge [17; 18]. Idealising the role of knowledge, followers of the theory warn against excessive protection of intellectual property rights, and suggest that in the context of growing information asymmetry between developed and developing countries, certain restrictions on free trade may be justified [19]. Thus, the development of national policy based on the latest theory of economic growth is associated with such endogenous factors as human capital, knowledge flow, and information technology.

Another round in understanding the nature of economic growth is associated with the theory of property rights, which in the classical formulation pays attention to the historical and institutional contexts of the development and changes of property rights, and in the modern one focuses on modelling the property structure using advanced mathematical tools [20]. Recognition of the importance of guaranteeing property rights for the modern economy development prioritises documenting legal property rights that allow businesses to receive loans and function effectively [21]. In less developed countries, such guarantees are limited, which leads to the emergence of shadow economies and a decrease in official business activity [22]. Thus, from the standpoint of this theory, the lack of official property rights is the main cause of poverty and restrictions on economic development.

METHODOLOGY

The research methodology was developed according to the key idea – identification of influencing factors and differentiation of economic growth models for different groups of countries around the world. Information basis of this study included resources of international analytical organisations and databases, which accumulate world development statistics by world country (*Global footprint network* [23] – Ecological footprint per capita; *United Nations Development Programme* [24] – Gender Inequality Index and Human Development Index; *World intellectual property organisation* [25] – global innovation index; *KOF Swiss Economic Institute* [26] – index of globalisation; *Resource trade earth* [27] – resource export and import). The choice of existential parameters of the functioning of countries for analysis was

substantiated by the purpose of this study, namely the intention to establish the impact of social, environmental, and innovation factors, as well as involvement in international trade, globalisation of countries on their development level. The Inclusive Development Index (IDI) was used as an indicator of the development of the world's countries. IDI is the result of a systematic initiative of the World Economic Forum, which aims to inform and ensure sustainable and comprehensive economic progress by expanding public-private cooperation through leadership and opinion analysis, strategic dialogue and cooperation. It has a high heuristic potential for conducting research and considers three categories of indicators – growth and development, inclusivity, generational continuity, and sustainability of development [28]. IDI covers 103 countries of the world, divided into two groups according to the index value (from 1 to 7) – advanced economies (29 countries – Norway, Iceland, Luxembourg, Switzerland, Denmark, etc.) and growing ones (74 countries – Lithuania, Hungary, Azerbaijan, Latvia, Poland, etc.) [29]. Due to the lack of data on the value of individual indicators, 9 countries were excluded from the study groups (Iceland, Nicaragua, Burundi, Nigeria, Madagascar, Sierra Leone, Mauritania, Chad, Lesotho) upon the analysis.

The methodological tolls of this study are based on methods of descriptive statistics, correlation analysis, and step-by-step regression. To process empirical data on the achieved level of inclusive development of the countries, as well as their inherent socio-economic, environmental, innovation, and globalisation parameters, their systematisation, visualisation, as well as quantitative description using the main statistical indicators, the authors of this paper employed the *descriptive statistics method*. To prove the existence and determine the nature of the correlation between the inclusive index and the countries' development parameters under study (advanced and growing economies), the method of *correlation analysis* was applied. The model of interdependence between performance and factor characteristics was constructed based on *step-by-step regression* – a method for selecting regression models, where the predictive variables are selected using an automatic procedure (in the form of a sequence of F-tests or t-tests).

RESULTS AND DISCUSSION

Conceptual framework of modelling

The development of the world's countries takes place in heterogeneous conditions and has different targeting, but the main target of evolutionary, and in some cases, revolutionary strategies, is socio-economic growth. Reinterpretation of the conventional, economically oriented development paradigm, where industrialisation and efficiency are the main drivers of growth, has led to the emergence of a new model of perception of development. It is based on the concept of inclusivity, that is, a form of development covering the entire spectrum of civil and political rights, idealising the dependence of society on considering the needs and opportunities of all categories of people [30], shifts the focus to human development and growth of their well-being and negating poverty and inequality [31].

The transmission of development values has led to the improvement of methodological approaches to its assessment. To replace the classic indicator of economic development (GDP per capita), an alternative option was developed – the Inclusive Development Index (IDI).

The methodology of this study is based not only on the grouping of countries of the world according to the value of the IDI, but also their gradation depending on the qualitative perception of progress made at the national and international levels, the strategies, and tools used to implement development goals, factors influencing the trajectory of the evolution of societies and economies. To identify the dependence of the IDI (Y) on the parameters of human development, the environmental burden on the environment, and the openness of economies in the global space, regression models were constructed for groups of leading and growing economies with the inclusion of the following variables:

– x_1 is the Ecological footprint per 1 inhabitant, gha/per person;
– x_2 is the Gender Inequality Index;
– x_3 is the Human Development Index (HDI);
– x_4 is the Innovation Index;
– x_5 is the Globalisation Index;
– x_6 is the cost of exported resources, billion US dollars;
– x_7 is the cost of imported resources, billion US dollars.

The simulation results demonstrated the availability of substantially different correlations between the selected factors and the performance feature for each of the groups of countries under study, which indicates the need to distinguish further analytical steps.

Modelling the development of leading countries by existential parameters

Results of modelling the dependence of the development level of leading countries on a combination of factors x_1-x_7 (Table 1) demonstrated the need to exclude gender inequality and innovation indices from further analysis, as well as the cost of exported resources, considering the statistically unac-ceptable value of their probability (*p-value*).

Table 1. *Descriptive statistics of the dependence of the inclusive development level in leading countries on factors x_1-x_7*

No.	Variables	Mean	Sd	Median	Trimmed	Mad	Min	Max	Range	Skew	Kurtosis	Se
1	Y	5.08	0.60	5.09	5.10	0.52	3.70	6.08	2.38	0.24	0.47	0.11
2	x_1	5.88	2.27	5.15	5.53	1.19	4.00	15.82	11.82	2.94	10.17	0.4
3	x_2	0.10	0.09	0.08	0.09	0.04	0.04	0.50	0.46	3.33	12.34	0.02
4	x_3	0.91	0.03	0.92	0.91	0.03	0.85	0.95	0.10	0.57	0.44	0.00
5	x_4	51.63	6.91	51.55	51.69	7.04	36.80	66.10	29.30	0.03	0.55	1.31
6	x_5	84.99	4.01	84.68	85.11	4.23	76.82	91.19	14.37	0.22	0.95	0.76
7	x_6	83.30	92.59	58.10	69.83	61.01	5.60	425.00	419.40	1.91	4.14	17.50
8	x_7	97.95	110.59	41.35	82.03	48.93	6.60	465.00	458.40	1.53	2.08	20.90

Source: *authors' own research.*
Note: *variables – variables; mean – average value; sd – mean square deviation; median – median; trimmed – weighted average value; mad – mean absolute deviation; min – minimum value; max – maximum value; range – range of variations; skew – skewness coefficient; kurtosis – excess coefficient; se – standard error*

The next stage of the study involved the construction of a matrix of correlation fields of dependences of factor and effective features (Fig. 1). Graphical interpretation of the results of correlation analysis demonstrates the presence of a statistically significant correlation between the IDI and the environmental footprint of countries (the correlation coefficient is 0.434), human development indices (0.743), innovation (0.550), and globalisation (0.450).

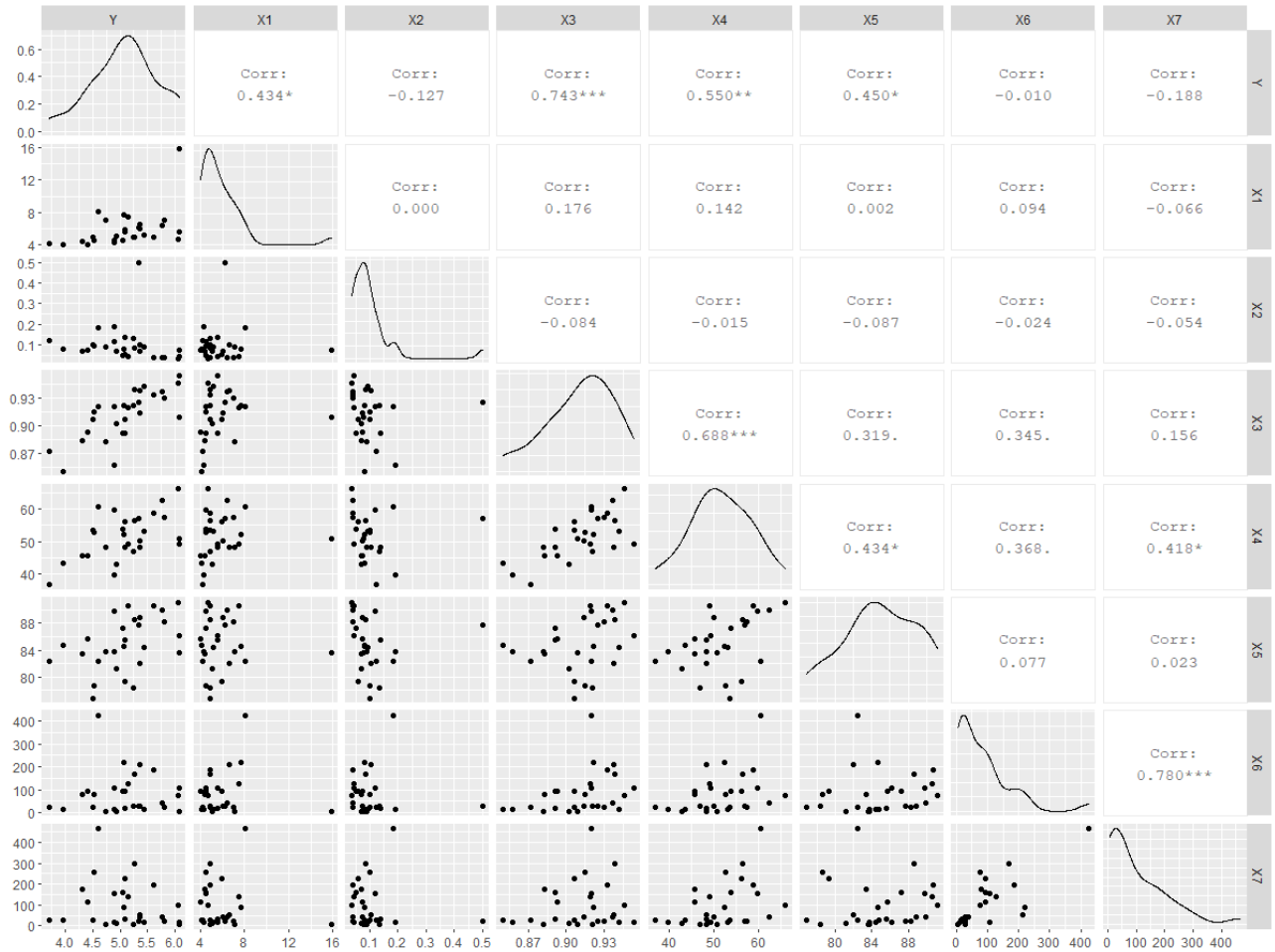

Figure 1. *Correlation matrix of developmental inclusivity index dependencies leading countries from the factors under study (x_1-x_7)*

Source: *authors' own research*

Applying regression analysis capabilities (Fig. 2) proves that despite the discovered correlations between factor and performance characteristics, the economic and mathematical model of the impact on the level of inclusivity of development of the studied group of countries includes only such factors as x_1 (Ecological footprint per 1 inhabitant, gha/per person), x_3 (Human Development Index), x_5 (Globalisation Index), and x_7 (cost of imported resources, billion US dollars).

```
1m(formula = Y ~ X3 +X7 +X1 +X5, data = data)

Residuals:
     Min       1Q   Median       3Q      Max
-0.66618 -0.16368 -0.01739  0.21267  0.68448

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.207e+01  2.170e+00  -5.564 1.16e-05 ***
X3           1.500e+01  2.451e+00   6.121 3.04e-06 ***
X3          -1.509e-03  5.455e-04  -2.766   0.0110 *
X1           7.957e-02  2.665e-02   2.986   0.0066 **
X5           3.725e-02  1.564e-02   2.381   0.0259 *
---
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.308 on 23 degrees of freedom
Multiple R-squared: 0.7789,  Adjusted R-squared: 0.7404
F-statistics: 20.25 on 4 and 23 DF, p-value: 2.895e-07
```

Figure 2. *Results of regression analysis of the influence of factors x_1-x_7 on the inclusivity level of development of the leading countries in the R-Statistics software environment*

The regression model has the following form (1) and reflects the positive impact of the growth of the environmental footprint, Human Development and Globalisation Indices on increasing the level of inclusivity of development in the leading countries, as well as the adverse impact of increasing the cost of imported resources.

$$Y = -1.207 + 7.957x_1 + 1.500x_3 + 3.725x_5 - 1.509x_7 \quad (1)$$

Thus, proceeding from the simulation results, the following intermediate conclusions can be drawn:

1. Despite the prioritisation of sustainable development ideas at the international level, integration of efforts to overcome the environmental consequences of globalisation processes, promotion of social responsibility of business and civil society, the presented model proves that economic growth of even highly developed countries is based on resources and growth of Ecological footprint. Furthermore, the countries included in the group of leading ones, according to the methodology of the World Economic Forum, are leaders in the scale of resource use, namely the absolute championship in this rating is assigned to Luxembourg, whose Ecological footprint is estimated at a record 15.82 gha/person; the second and third positions are occupied by the United States and Canada with 8.1 and 7.7 gha/person, respectively. Consequently, the policy of reducing the environmental footprint as an element of the implementation of the Sustainable Development Goals is debatable, given the permanent desire for economic growth.

2. The simulation results prove the adverse impact of increasing the cost of imported resources, which reduces the prospects of strategies to compensate for the need for them due to imports and thus reduce the load on the endogenous natural resource potential of countries. Moreover, the trade balance of resources trade involving the studied group of countries indicates their total import dependence, except Norway, which exports 6 times more resource goods than it imports, New Zealand – 3.1 times, Canada – 2.5 times.

3. The Gender Equality Factor has not acquired statistical significance for consideration in the constructed model, since for the group of countries studied, its value ranges from 0.182 (USA) to 0.037 (Switzerland), which is evidence of the special progress they have made in the field of equality of rights and non-discrimination based on gender (*for comparison – the index value for Ukraine is 0.284, which determines the 60th position of the country in the world ranking*). Furthermore, they are leaders in the field of human development, belong to the group of countries where its level is extremely high (forming the top-30) [32].

Modelling the development of developing countries by existential parameters

In contrast to the patterns established for leading countries, the results of statistical analysis of the dependence of the level of inclusivity of development of growing countries on the multitude of factors x_1-x_7, the

authors of this study proved the existence of a paired correlation between them and the effective feature (Table 2), except for indicators of international trade in resources.

***Table 2**. Descriptive statistics of the dependence of the inclusive development level in developing countrieson factors x_1-x_7*

No.	Variables	Mean	Sd	Median	Trimmed	Mad	Min	Max	Range	Skew	Kurtosis	Se
1	Y	3.84	0.56	3.98	3.86	0.55	2.47	4.86	2.39	-0.36	-0.78	0.07
2	x_1	2.48	1.40	2.10	2.30	1.19	0.70	7.60	6.90	1.34	1.97	0.17
3	x_2	0.38	0.13	0.38	0.38	0.14	0.12	0.68	0.56	-0.15	-0.80	0.02
4	x_3	0.71	0.11	0.74	0.72	0.09	0.43	0.87	0.44	-0.71	-0.52	0.01
5	x_4	29.54	7.22	28.80	29.15	8.15	18.70	53.30	34.60	0.56	0.08	0.90
6	x_5	65.43	10.15	66.28	65.50	10.04	45.44	84.98	39.54	-0.10	-0.90	1.26
7	x_6	32.32	60.55	7.50	18.83	8.90	0.17	382.00	381.83	3.61	15.82	7.51
8	x_7	33.48	104.96	6.90	14.27	7.71	0.22	801.00	800.78	6.23	41.55	13.02

***Source**: authors' own research.*
***Note**: variables – variables; mean – average value; sd – mean square deviation; median – median; trimmed – weighted average value; mad – mean absolute deviation; min – minimum value; max – maximum value; range – range of variations; skew – skewness coefficient; kurtosis – excess coefficient; se – standard error*

Using correlation analysis (Fig. 3), it was established that the highest level of close correlation is observed between the value of the IDI and the Human Development Index (0.817), the Globalisation Index (0.645), the Innovation Index (0.578) and the environmental footprint per 1 inhabitant (0.551). Notably, an inverse correlation with a high level of significance was found between the indices of inclusive development and gender inequality (-0.673). This conclusion contradicts conventional ideas regarding the impact of gender discrimination on social and economic development, since Gender Equality Index constitutes an indicator not only of the maturity and quality of human capital, but also an integral attribute of targeting in economic growth strategies and policymaking.

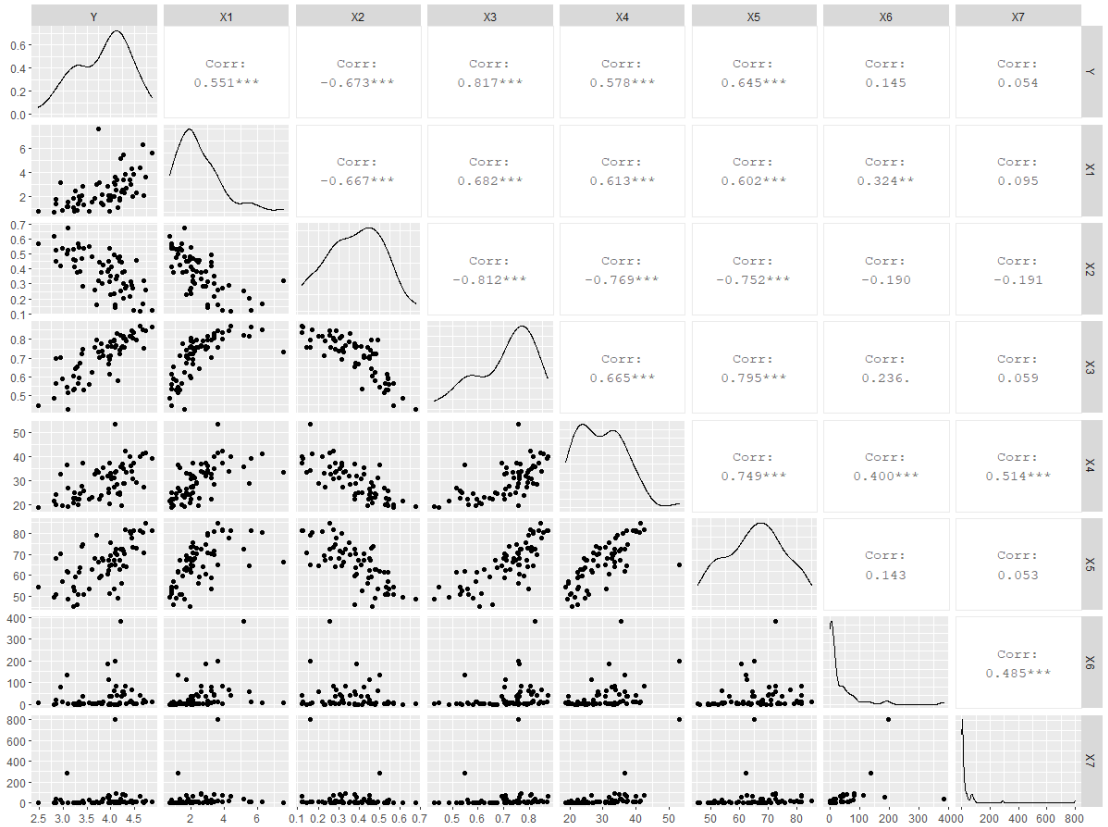

***Figure 3**. Correlation matrix of developmental inclusivity index dependencies developing countries from the factors under study (x_1–x_7)*

***Source**: authors' own research*

Regression analysis of a set of selected factors influencing the inclusive development of growing countries of the world (Fig. 4) narrowed it down to only one – the Human Development Index (x_3). Thus, the regression model of the problem under study in the plane of established factors ($x_1 - x_7$) takes the following linear form (2):

$$Y=0.9519+4.0708x_3 \quad (2)$$

```
1m(formula = Y ~ X3, data = data)

Residuals:
     Min       1Q   Median       3Q      Max
-0.96147 -0.16156  0.04878  0.17835  0.84109

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)    0.9519     0.2598   3.664 0.000511 ***
X3             4.0708     0.3620  11.245   <2e-16 ***
---
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3243 on 63 degrees of freedom
Multiple R-squared: 0.6675,  Adjusted R-squared: 0.6622
F-statistics: 126.4 on 1 and 63 DF, p-value: < 2.2e-16
```

Figure 4. *Results of regression analysis of the influence of factors x_1-x_7 on the inclusivity level of development of the developing countries in the R-Statistics software environment*

Thus, the constructed model argues the necessity of priority concentration of efforts and internal political initiatives in the developing countries on measures to stimulate human development. It is the evolutionary leap in the quality of human capital that creates prerequisites for the implementation of innovations in economic systems, taking advantage of the openness of the economy and globalisation processes, namely international trade in general, since its raw material component at this point does not affect overall growth.

The proven dependence of the development of countries with growing economies on their human capital points at the understanding of the main priority of their development models – stimulating the growth of human development, without which the effects of internationalisation of business, growth of labour productivity and investment, economy technologisation remain insufficient to achieve the sustainability goals. Similar ideas are argued in numerous modern studies implemented with evidence from countries of this group. In particular, K. Wang and R. Jiang, upon determining the correlation between carbon emissions and the level of development of the BRICS countries, discovered that Russia and the Republic of South Africa (the Human Development Index for which is 0.824 and 0.725, respectively) managed to break this dependence, achieving a sustainable effect of weakening the energy intensity of economic growth. Instead, for India (HDI=0.547), the extensive correlation between economic growth and energy consumption persists [33]. Consequently, the BRICS countries are described by a stable dependence of the nature of economic development on the achieved level of human development.

The importance of the achieved level of human development in the model of international business expansion, expressed through entrepreneurial skills and the ability to develop social capital, is also proved in studies of small and medium-sized social enterprises in China during their internationalisation [34]. F. Vorkadel and E. Arakil express their solidarity on the role of human development in the growth model of international business. Based on quantitative and qualitative indicators of TNC activity, they identify elements of corporate social responsibility aimed at institutional and social, human-centred changes in countries with growing economies, namely the development of institutional and subsidiary entrepreneurship, support for initiatives of stakeholder groups [35].

The interdependence between migration processes, investment in education and economic growth of labour donor countries, modelled in the study of Z. Benhamu and L. Kassin using the example of the Caribbean, proved the duality of the importance of human development for emerging countries. On the one hand, the educational component of human capital development constitutes a priority for investment by migrant workers, and on the other hand, it is a factor in stimulating further economic growth of countries. In other words, migration creates a substitution effect between savings and human capital [36]. However, according to the results of a study by A. Sarvar et al., human capital becomes of real importance for the country's growth in the presence of an established financial system that functionally provides opportunities for access to education, an increase in the number of schools and highly qualified teachers in different regions [37]. An alternative view of the problem

of infrastructure support for human development is observed in a study conducted using evidence from Columbia universities [38]. Its results point at the necessity of supporting the intellectual capital of universities, which is being transformed into opportunities for the development of the country's human capital through education, research, and innovation. Therewith, it is necessary to agree with the authors of the study on the importance of state support for increasing the critical mass of higher education institutions for the development of progressive research and development centres, the involvement of students and teachers in international mobility programmes.

Proceeding from the results obtained in this study and the results obtained by other researchers of the development features of countries with emerging economies, it can be concluded that it is necessary to ensure a complementary supplement to the human-centred growth model with measures that solidify the conditions for the multiplication of human capital, namely:

– transformations of the institutional environment aimed at realising the entrepreneurial potential;

– activation of initiatives within the framework of corporate social responsibility of international companies (development of the social environment for doing business and directly the staff of business structures);

– development of competencies in the field of financial literacy and management of financial resources;

– adaptation of teaching standards and methods to the requirements of world practice, development of the academic environment and technologies of educational and scientific networking.

CONCLUSIONS

The problem of development has a consistently high relevance and multidimensional nature of attempts to study, which combine evolutionary theoretical concepts and modern practical patterns identified during empirical developments. A special feature of this study is the intention to model the correlation between the level of inclusivity of development of the world's countries and the parameters of human development achieved by them, innovation and globalisation of national economies, involvement in international trade in resources and the environmental burden on the natural environment. The results of this study proved that despite the direct or indirect impact of the analysed factors on the economic development of the world's leading countries and countries with growing economies, there is no universal model that would reflect the real content of the economic growth process. Development is a multidimensional process that involves extensive structural changes in the economic, social, environmental, and political areas; therefore, it is difficult to create a single model that would contain the standards and values of world civilisation, the features of global economic and political systems.

The use of statistical analysis and modelling methods allowed differentiating the dependence of their level of development on the investigated parameters for the groups of countries under study. Despite the priorities of sustainable development and their implementation in global strategies, the economic growth model of the world's leading countries is always based on the use of natural resources, including imported ones. This suggests that their leading role in shaping the Ecological footprint of humanity on the planet will continue to be preserved. At the same time, the growth model of the world's leading countries is based on the positive nature of the interdependence between inclusive development and globalisation, the characteristics of human capital. The model created for countries with growing economies proved a different format of dependence. In particular, it was discovered that for a group of such countries, human development remains the main factor of development. Therefore, the quality of human capital should become a priority for shaping the ideology of economic growth, national reforms, and policies.

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Інклюзивність розвитку країн світу в умовах глобалізації економіки: моделі та аргументи

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Анотація. Стаття присвячена дослідженню особливостей економічного зростання в різних за рівнем розвитку країнах світу, для яких характерними є відмінності не лише в досягнутих показниках росту, а й траєкторії та характеру стимулювання цього процесу. Метою дослідження є оцінка впливу екзистенційних параметрів функціонування країн (провідних і зі зростаючою економікою) на інклюзивність їх розвитку в умовах глобалізації економіки, а також обґрунтування пріоритетних напрямів суспільно-політичних та економічних змін, направлених на реалізацію потенціалу росту відповідно до концепції сталості. Методичну основу дослідження становлять методи описової статистики, кореляційного аналізу та покрокової регресії. Як основний показник розвитку країн світу використано індекс інклюзивності розвитку, що рекомендований Світовим економічним форумом. Інформаційною базою дослідження є міжнародні бази даних, що представляють дані в розрізі країн світу. Результати дослідження дали змогу визначити основні чинники розвитку економік та виявити залежність економічного зростання окремо провідних і розвиваючих країн світу. Доведено, що незважаючи на прямий чи опосередкований вплив даних факторів на економічний розвиток провідних країн світу та країн із зростаючою економікою, універсальної моделі, яка б забезпечувала економічне зростання з орієнтацією на сталий розвиток, не існує. Проте можливим є визначення групи факторів, що забезпечують максимальний ефект економічного зростання. Так, для країн із зростаючою економікою пріоритетом є людський розвиток, а для провідних країн світу економічне зростання переважно забезпечується дією таких чинників, як екологічний слід на одну особу, індекс людського розвитку, індекс глобалізації та вартість імпортованих ресурсів. Динамічність змін у глобальному просторі, тенденції до подальшого розвитку людського капіталу в усіх країнах світу, непрогнозованість наслідків впливу пандемії COVID-19 визначають перспективність подальших досліджень у започаткованому напрямі

Ключові слова: глобалізація, диференціація, інклюзивний розвиток, економічне зростання

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Formation of an Innovative Business Model of a Trade Organization in the Context of Economic Globalization

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Abstract. The development of Ukrainian trade organizations in ordinary conditions is characterized by a high degree of inertia. Therefore, when situations that need to change arise, business strategies of market participants also change dramatically. Most often, such transformations are connected with external factors, such as the overall economic crisis, a sharp change in the state "rules of the game" in a particular sector of economic relations, as well as another external factor bond to the occurrence of new serious competitors. The development of organizational and economic mechanism to ensure the innovative development of retail trade, requires comprehensive consideration of internal and external factors of the studied system, the formation of strategies and programs to increase the innovation potential of its participants, their active interaction, increasing the use of innovative technologies, generating ideas and transformations. The article considers the issues related to the impact of business globalization processes on the transformation of business models of trade organizations and their operation strategy, as the degree of trade development indicates the standard of living and the state of the economy and society. The authors of the article suggest that retail organizations adapt to the changes in the macro and micro environment, using innovative components in economic and financial activities, which will ensure their competitiveness and prevent crises. The proposed model of an innovative trade organization allows to identify the goals components of innovation activities, which combine the strategic guidelines of the state regulation and help to improve the economic condition of trade organizations

Keywords: trade organizations, retail trade, globalization, innovations in retail trade, strategy, multichannel trade

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INTRODUCTION

Effective business activity is a source of economic growth, which ensures employment in the country and directly affects the quality of life of the population [1]. Intensification of competition of domestic and foreign markets, the occurrence of its new forms, differentiation of consumer demand require the search for new directions for the formation of competitive advantages of trade organizations in the context of globalization [2]. Retail trade, being the branch of the economy closest to the final consumer, serves as the main tool for regulating the main components of the production process (volume and range of products) and allows to monitor consumer preferences, the dynamics of quali-ty of life and much more [3]. Thus, to meet the growing needs of the population, trade organizations need to constantly improve their activities, offer competitive advantages, transform their business models, especially under the influence of globalization of economic processes. All the above-mentioned factors prove the relevance of the study [4-6].

Problems of innovative development of trade organizations have been studied in the works of such scholars as P. Hrynko [7; 8]. If we consider the development of forms of retail trade in the last decade, researchers have studied and offered various theories in this regard: cyclical, environmental and based on conflict theory. Cyclical theories include: "the wheel of retail", one of the main ecological (environmental) theories is the evolutionary theory of A. Drismann, which was developed in the works of M. Forrester and K. Davis [9; 10]. The conflict theory presupposes that under the influence of competitors, retailers must replace their forms of activity with more efficient ones, introducing innovations into their development in order to gain a more favorable position on the market [11]. As for the term "retail innovation", many scientists, including the western ones, do not distinguish it from the general term "innovation", although they have their own characteristic features that are to be justified. The tendencies of functioning of multichannel model of trade are considered as the increase of competitiveness of the trade organizations depends on its organization [12-14]. Using the SCOR-model, which identified main indicators for evaluating the performance of logistics activities, makes it possible to generate competitive advantages in trade enterprises [15; 16].

MATERIALS AND METHODS

The following scientific methods and techniques were used the research: observation, sampling and grouping – for theoretical grounding in determining the problems and trends of the research topic; a systematic approach to build an innovative model of trade organizations; logical-structural and graphic modeling to illustrate the essence of the phenomena, the relationship between elements of the system; generalization and comparative analysis to form a strategy for managing innovative development, clarification of the conceptual apparatus.

Facing the threat of invasion global network operators in the Ukrainian market, domestic trade organizations have to intensively mobilize resources and develop new development strategies. At the same time, they demonstrate high abilities to adapt organizational forms of sales technology to global retailers that already exist in the world. Despite researchers' different approaches to understanding the reasons for the change in forms of retail trade, each group of theories emphasizes the need for innovative development of trade organizations as a condition to ensure profit gain and their long existence in the market. Thus, in our opinion, in order to ensure the stability of retail organizations, it is advisable to adapt to the changes in the macro- and micro-environment and use innovative components that ensure competitiveness and counteract crises in economic and financial activities.

Innovation is needed for the innovative development of trade organizations. Regarding the term "innovation in retail", many scientists do not distinguish it from the general term "innovation". Despite this fact, we believe that "innovation in retail" has its own characteristic differences, emphasizing the peculiarity of innovation activities in this area. One of the international methodological standards, OECD Oslo Guide [17], defines four types of innovation in trade: product innovation; process innovation; marketing innovation; organizational innovation. These innovations can be new to the firm / institution, to the market / sector or to society as a whole. We believe that "innovations of trade organizations in the globalization of economic processes, using their mechanisms, provide a process of creating new forms and technologies of offering goods and services, improving logistics, marketing, management concepts, influence the transformation of business models and aim to improve competitiveness, ensuring a positive socio-economic and commercial effect". The key components of trade include: creativity, strategy, implementation, profitability. At the same time, innovations in trade should have such features as novelty, security, compatibility, competitiveness, mobility, etc. The application of innovations in retail provides an opportunity to obtain the following benefits: the efficiency of delivery of goods from producer to consumer increases; the process of using the main working capital of the organization is improved; costs on using innovative technologies, modern equipment, the Internet are reduced; document circulation is reduced, its reliability is increased due to innovative information systems; labor productivity of human resources increases through the prism of innovation culture, the quality of trade services, improved working conditions. In addition, innovations can be applied in changes in the characteristics of the product, trade and technological process, which affect the positive

dynamics in increasing turnover, profit and are not associated with significant investment. This makes it possible to reach the biggest part of the target audience, improve the quality of customer service and, as a result, contribute to the efficiency of economic activity. The role of innovation in retail, ultimately, is reduced to the trade employees' comfort and the process of purchasing goods by buyers, ensuring high quality trade services.

In order to implement innovative activities in trade organizations, a systematic approach is needed, which considers innovations as a part of the system, the successful operation of which is possible only with the integrated interaction of its elements, one of which is knowledge. In our opinion, the formation of an innovative model of a trade organization in general involves effective knowledge management, risk management, as well as analysis and selection of optimal sources of innovative projects funding. The transfer of retail organizations to an innovative path of development involves designing their innovative model (Fig. 1), which combines the strategic guidelines of the state regulation and improves economic conditions of trade organizations. To accomplish this, it is appropriate to develop and scientifically prove the block of mechanisms and tools of innovative development of retail trade.

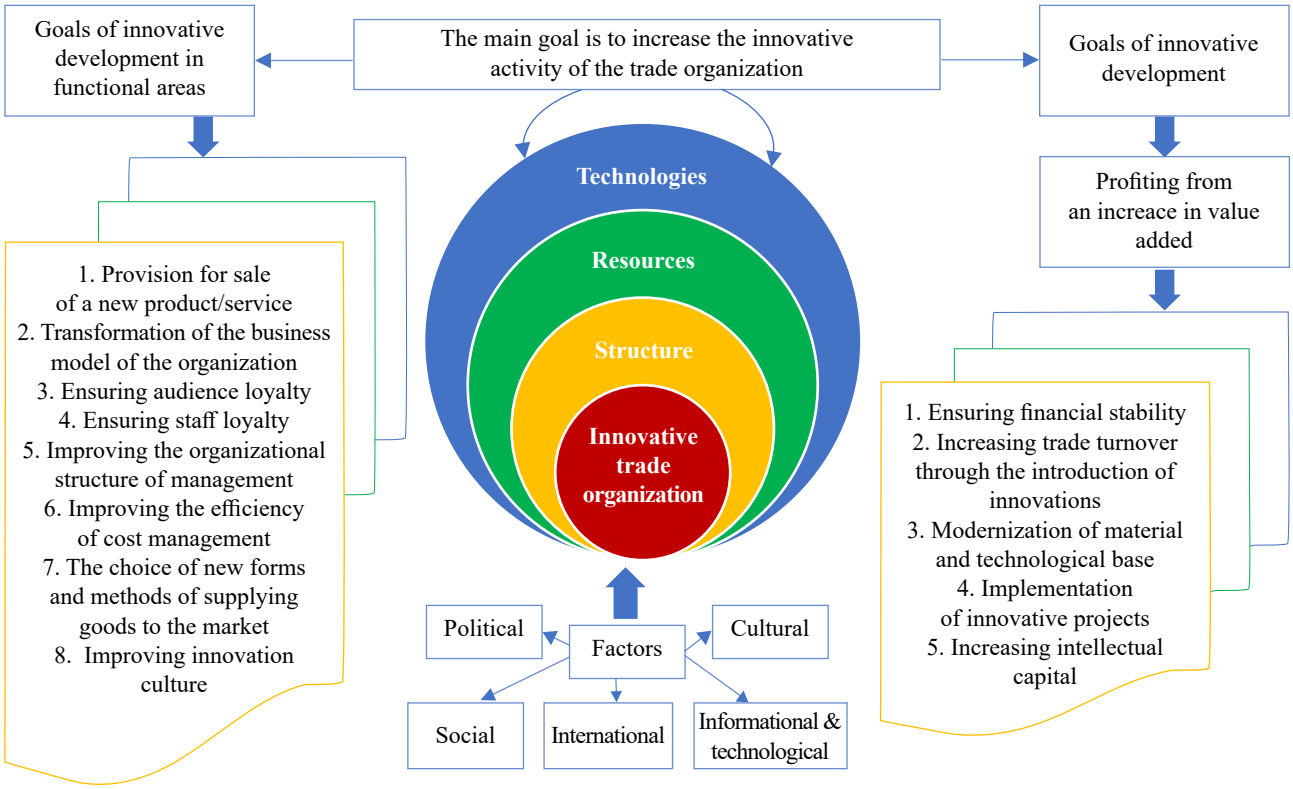

Figure 1. *Model of innovative trade organization*

Having analyzed foreign experience, trends in the functioning of the multi-channel model of trade were identified. The creation of an Internet commerce channel in digital economy is extremely common. Diversification of distribution channels allows to strengthen the organization's position on the market, significantly expand the target market, customer base, to obtain additional profit.

In order to design a successful model of multi-channel trading, it is necessary to focus on customer-oriented marketing strategies. For example, one of the best-known technologies for building effective relationships with customers is a system of loyalty cards. It is proved that it motivates consumers to use the opportunities of multi-channel trade of the enterprise. Another technology is the use of systems for returning, exchanging, repairing and delivering the purchased goods.

A trading organization that has decided to implement a system of multi-channel trading may face a number of difficulties:

- First, an ability to simultaneously focus on and manage different types of business activities.
- Second, specific characteristics of the sold goods may not correspond the format of e-commerce.
- Third, it is necessary to carefully study the needs of consumers when using multi-channel trade of the organization.
- Fourth, a serious problem is the creation of IT infrastructure – retailers face significant financial expenses, which can be unjustified if customer needs are insufficiently researched.

In order for multi-channel trade to be implemented successfully, it is necessary to transform the

business model of the organization of retail trade. There are three components to which major changes should be directed: the format, activities, management system.

In our opinion, in order to effectively develop a strategy for the implementation of multi-channel trade, it is necessary to follow the methodology for its development (Fig. 2).

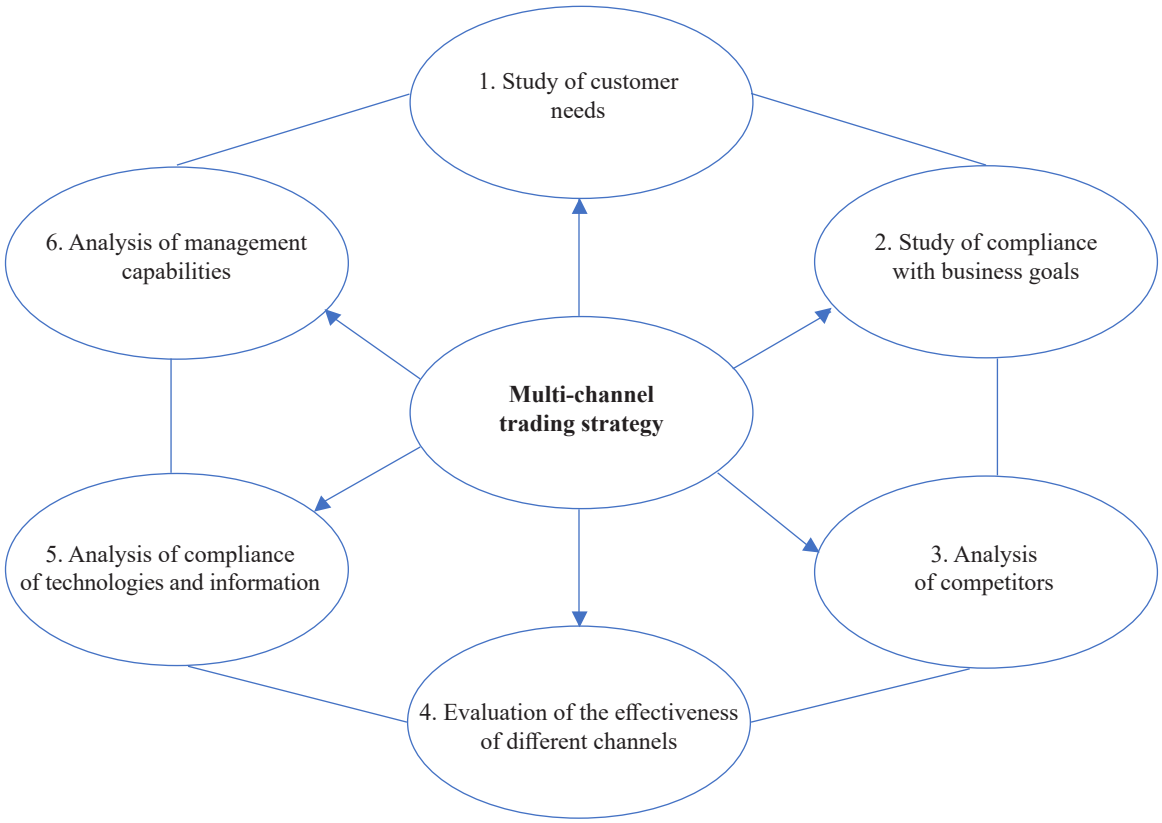

***Figure 2**. Model of multi-channel trade development methodology*

RESULTS AND DISCUSSION

After assessing all the factors considered in this methodology, a trade organization can use the following strategies to implement a multi-channel model of trade:

1. Identification of general synergy interconnections between the key elements of different forms of trade. There are similar elements in traditional and electronic forms. In particular, common infrastructure – warehouses, delivery system; general marketing strategy; common target market. For effective management of multi-channel trade, it is necessary to ensure maximum compliance through clear coordination and control, as well as the adjustment of goals, the structure and opportunities in both formats.

2. The use of common resources of both the traditional the electronic model of trade. Of course, an organization implementing e-commerce as an additional channel can take advantage of such a traditional model as increasing the security of purchases for consumers. This is explained with the existence of a real store, where buyers can come to solve the problems that arose while buying goods. In its turn, e-commerce to a greater extent provides opportunities to accumulate and analyze a significant amount of information about consumers and their preferences.

3. Development of a hybrid model that can combine the advantages of each form of trade. Based on a combination of business elements of e-commerce and traditional commerce models, we have identified a combined model that allows to take the advantage of both formats (Table 1).

4. Resolving conflicts that arise between trade channels. Conflicts and possible solutions to them, which are often encountered during the implementation of a multi-channel retail system, are given in Table 2.

***Table 1**. The combined model of retail channels*

The characteristics of a business model	Traditional form of trade	E-commerce form of trade	The combined model
The advantages of the form	The ability to choose and realistically assess the quality characteristics of goods	The reduction of expenses; Individual work with clients; Multi-format advertising; An opportunity to work around the clock; New forms of partnerships (e.g. dropshipping)	Personalization of purchases; Multi-format advertising; An opportunity to choose and estimate the goods; Optimal pricing
Key assets	Store location, infrastructure, logistics, brand	Information technologies, database; An opportunity to use the mechanisms of the digital economy; Intellectual capital	The existence of a virtual and physical store; Wider market coverage and segmentation; Large customer base; High brand value
Profit model	Goods selling	Goods selling, micro segmenting of market	Goods selling, micro segmenting of market
Structure of major expenses	Rent, store maintenance, equipment, warehouses, staff salaries	Information technologies, initial costs for creating an online store, database, delivery channels, stock management	Initial costs for creating an online store; The cost of technical support for the online store; Rent, store maintenance, equipment, warehouses, staff salaries. The expenses on an item are minimized through synergy interconnections between the channels and an increased customer base

***Table 2**. Conflicts and options for resolving them during the implementation of a multi-channel retail system*

Major problem	The essence of the conflict	Options for resolving
Coordination of an organizational structure	The organizational structure is initially designed to provide conditions for the effective functioning of traditional trade, its infrastructure – warehouses, transport, equipment, shops. When a new channel is added, it creates difficulties in coordination, in the sequence of tasks of two or more channels	If an organization decides to implement a new channel (for example, an online store), it will need to transform the structure into an IT infrastructure. For example, change the method of warehousing so that employees can complete online orders quickly, introduce a home delivery system, and so on. Any changes that affect the structure must be explained to the employees at all levels, motivating them to support these changes and transforming the communication
Consumer perception	Customers do not trust online trade enough due to the inability to assess the quality of goods before purchasing, doubt the security of online payments, etc.	Retail organizations need to create sites with the simplest order system, a detailed description of the offered products, the availability of certificates. The payment system must be securely encrypted. It is possible to introduce bonuses, discounts for buying goods online
Resource capabilities of an organization	A retail organization faces many difficulties in implementing a new channel – lack of funding, lack of necessary technologies for integration, qualified staff	An organization can co-work with other organizations to increase its capacities. To technically ensure the quality of an online store, it is possible to outsource the staff

It is worth noting that small and large businesses are forced to constantly update and improve the management of innovative development, so as not to lose their position on the market. It is important to emphasize that in the era of informatization and dynamically changing interests of the audience it is advisable to approach the management of innovative development via mega-subjects – using the developments (approaches, concepts,

mechanisms, techniques, tools) from different fields of knowledge (innovation and traditional management, marketing, psychology, etc.) [18; 19].

We believe that the analysis of the innovation process from the point of different disciplines, as well as its synthesis with creative tools can lead to positive and original results. Under uncertain conditions, such a strategy can become a solid foundation for building a flexible, efficient and competitive innovation organization, ready to successfully respond to the challenges of the modern economy, thereby controlling the processes of creative destruction [20].

It is determined that modern strategic management provides effective tools for implementation and further sustainable development of the company innovation activity. These tools represent a gradual rebuilding of the strategy through the basic adoption of a market model of innovation activity, the assessment of the current state of the company in the market, the creation of structure, team and portfolio of innovations and the choice of the optimal innovative strategy for entering the market [8].

Based on the research results, we recommend that the choice of a strategy for innovative development of trade organizations should depend on various factors, such as market position and innovation potential, which determines the appropriateness of using a multifunctional form of retail trade. Methodical recommendations during the transformation of a business model of an organization of retail trade are offered; the characteristic features of multichannel trade, possible conflicts and options for their resolving while introducing a multichannel system of retail trade are defined. In our opinion, in order to effectively develop a strategy for the implementation of multi-channel trade, it is necessary to follow the proposed methodology, which allows not only to assess the appeal of the industry and innovation potential, but also to see problems in innovation development and find ways to solve them.

CONCLUSIONS

The development of organizational and economic mechanism to ensure the innovative development of retail trade requires a comprehensive consideration of the internal and external factors of the studied system, the formation of strategies and programs for its innovative development, generation of ideas and transformations. It is suggested that retail organizations adapt to the changes in the macro and micro environment, using innovative components in economic and financial activities, which will ensure their competitiveness and prevent crises. The innovative way of development of retail trade organizations involves the construction of their innovative model, which combines the strategic guidelines of the state regulation and helps to improve their economic condition. The existing theories of trade organizations development are studied in three groups: cyclical, ecological or environmental, and conflict theories, which, to a greater extent, apply to those organizations that carry out multichannel trade, among which a certain place is occupied by the Internet trade. The proposed model of an innovative trade organization allows to identify the goals components of innovation activities, which combine the strategic guidelines of the state regulation and help to improve the economic condition of trade organizations. To accomplish this, it is advisable to develop and scientifically prove the block of mechanisms and tools of innovative development of retail trade.

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Формування інноваційної бізнес-моделі торговельної організації в умовах економічної глобалізації

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Анотація. Розвиток українських торговельних організацій у звичайних умовах характеризується високим ступенем інертності. Тому під час виникнення ситуацій, які необхідно змінити, кардинально змінюються і бізнес-стратегії учасників ринку. Найчастіше такі перетворення пов'язані із зовнішніми чинниками, такими як загальна економічна криза, різка зміна державних «правил гри» в певній сфері економічних відносин, а також інший зовнішній чинник, пов'язаний із виникненням нових серйозних конкурентів. Розробка організаційно-економічного механізму забезпечення інноваційного розвитку роздрібної торгівлі, потребує всебічного врахування внутрішніх і зовнішніх чинників досліджуваної системи, формування стратегій та програм підвищення інноваційного потенціалу її учасників, їхньої активної взаємодії, формування організаційно-економічного механізму забезпечення інноваційного розвитку роздрібної торгівлі, збільшення використання інноваційних технологій, генерування ідей та перетворень. У цій статті розглядаються питання впливу процесів глобалізації бізнесу на трансформацію бізнес-моделей торговельних організацій та стратегії їх функціонування, оскільки ступінь розвитку торгівлі вказує на рівень життя та стан економіки й суспільства. Авторами статті запропоновано організаціям роздрібної торгівлі адаптуватися до змін макро- та мікросередовища, використовуючи інноваційні складові в господарсько-фінансовій діяльності, що забезпечить їх конкурентоспроможність і запобіжить кризовим ситуаціям. Запропонована модель інноваційної організації торгівлі дозволяє визначити цілі складових інноваційної діяльності, що поєднують стратегічні орієнтири державного регулювання та сприяють покращенню економічного стану торговельних організацій

Ключові слова: організація торгівлі, роздрібна торгівля, глобалізація, інновація в роздрібній торгівлі, стратегія, багатоканальна торгівля

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Introduction of Innovative Approaches in the Activities of Local Self-Government Bodies of Ukraine

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Abstract. The article is devoted to the problems of finding and introducing modern innovative approaches to the activities of local self-government bodies of Ukraine. It has been found that overcoming the problems of old and inefficient models and management methods that do not meet the requirements of modern communities is possible only through the development of high-quality and effective theoretical, methodical, organizational, and legal support for the process of local self-government. The definition of the concept of "local self-government" is summarized, using the regulatory margin and considering this concept in the context of modern realities, which now constantly face this institution of management. The author's interpretation of the category "local self-government" was developed for the needs of solving the problems and problems set out in the article. An organizational and legal mechanism for introducing innovative approaches to the activities of local self-government bodies has been developed as the main element of the definition of the category "local self-government." Problems related to the effective functioning of institutions for the provision of "electronic" public services have been investigated. Innovative approaches to improving mechanisms for the provision of "electronic" public services by local authorities have been developed and justified. A general methodology for reengineering the administrative and management processes of local self-government bodies in the form of phases and stages of its implementation has been developed. It was concluded that the continuous development of the system of local self-government does not allow the development of sustainable types of innovative approaches to solve problem areas of local self-government "forever," but requires the constant monitoring of foreign experience of advanced countries and the constant development of new and progressive innovative mechanisms that will continue to introduce decentralization reform and the creation of strong and effective local self-government bodies

Keywords: novel ways, municipalities, reengineering, organizational and legal mechanism, public service

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INTRODUCTION

The emphasis on the need to improve the approaches to the activities of local self-government of Ukraine has been placed since the beginning of the twentieth century, but the authorities did not pay significant attention to solving this problem and did not stimulate the introduction of innovative approaches in this process for a long time. But, recent trends indicate that in conjunction with the political activation of communities and the general strengthening of socio-political processes, state authorities have begun to find more justified approaches to solving the problems of organizing and ensuring the effective functioning of local self-government using foreign experience and innovative approaches.

However, it should be noted that the modern stage of the development of self-governing management is characterized by the use of old and inefficient management models and methods that do not meet the requirements of modern communities, as well as the low level of introduction of innovative technologies. Overcoming this problem is possible only through the development of high-quality and effective theoretical, methodological, and organizational and legal support for the process of local self-government. Also, the relevance of the article is due to European integration processes that have been taking place in Ukraine for more than five years, which causes compliance with relevant foreign norms and standards in public administration and local self-government.

Many scientific and methodological works of scientists of state administration, economics, management, and other fields of science are devoted to the introduction of innovative approaches in the activities of local self-government bodies of Ukraine, namely: O.M. Nepomnyashchyy, O.A. Marusheva, Yu.H. Prav, O.V. Medvedchuk, I.A. Lahunova, A.P. Lelechenko, V.I. Shariy, O.A. Diegtiar, N.S. Orlova et al. [1-3], N.I. Kosteniuk [4], M. Salvador, E. Pano [5], R. Yaslikaya [6], A.M. Sbragia [7], H. Ewens, J. van der Voet [8], T.O. Slobodeniuk [9], A.Yu. Gevorkyan [10], O.V. Kuzmenko [11], V.S. Kuibida, L.M. Smolova [12], O.I. Parhomenko-Kutsevil [13], G. Bel, R. Gradus [14], O.V. Vynohradova [15] and others. The above-mentioned scientists conducted studies of the problem presented in the article, provided theoretical and methodological and practical recommendations for solving them. However, in these works, the issues of developing an organizational and legal mechanism for introducing innovative approaches to the activities of local governments, with the help of which it is possible to justify proposals and recommendations for introducing innovations in this area, remain incomplete.

The purpose of the study is to develop proposals and recommendations on the introduction of innovative approaches to the activities of local self-government bodies of Ukraine. To achieve the purpose, there were set the following objectives in the article:

– to summarize the definition of the concept of "local self-government" and provide an updated author's interpretation;

– to develop an organizational and legal mechanism for introducing innovative approaches to the activities of local self-government bodies;

– to develop and justify innovative approaches to improve mechanisms for the provision of "electronic" public services by local self-government bodies;

– to develop a general methodology for the reengineering of administrative and management processes of local self-government bodies in the form of phases and stages of its implementation [16; 17].

MATERIALS AND METHODS

At the present stage, any democratic state has the effective development and functioning of the institution of local self-government as its main objective. Therefore, it is important to generalize the definition of "local self-government," using it as a regulatory margin, and considering this concept in the context of modern realities, which now constantly face this institution of management. From the point of view of the regulatory margin, it is useful to consider the category "local self-government" through the prism of the definitions given in Table 1.

***Table 1**. Comparative analysis of the content of the concept of "local self-government" in regulatory documents*

No.	Regulatory document	Content of the concept	The main subject
1	European Charter of Local Self-Government [18]	Means the right and real capacity of local authorities within the framework of the law to regulate and manage a significant proportion of public affairs, under their responsibility and in the interests of the local population	Authorities at different levels
2	Constitution of Ukraine [19]	Is the right of a territorial community – residents of a village or voluntary association of residents of several villages in a rural community, a settlement, and a city – to independently resolve issues of local importance within the framework of the Constitution and laws of Ukraine	Territorial community
3	Law of Ukraine "On Local Self Governance in Ukraine" [20]	Is the right and real ability of a territorial community – villagers or voluntary association in a rural community of residents of several villages, the settlement, the city to resolve issues of local value within the Constitution and laws of Ukraine independently or under the responsibility of bodies and officials of local government, guaranteed by the state	Territorial community (now the amalgamated territorial communities are becoming relevant)

***Sourse**: [18-20]*

As can be seen from Table 1, in defining the concept of "local self-government," the European Charter of Local Self-Government [18] is more aimed at clarifying and supporting the specific functions of the authorities, while the Constitution of Ukraine [19] and the Law of Ukraine "On Local Self-Governance in Ukraine" [20] interpret this concept more in terms of its belonging to the territories and commune (community) that lives or works in this territory. A synthesis of the current scientific thoughts of well-known scientists of different branches of government and management on the issue of determining the definition of the category "local self-government" at the current stage of the development of Ukraine can be illustrated in Figure 1. Having generalized the main directions of the definition of the concept of "local self-government" by highlighting the universal definition of this concept, the features, functions, and principles that scientists distinguish in their scientific papers (Fig. 1), it is possible to make an author's interpretation of the category for the needs of solving problems and challenges specified in the article.

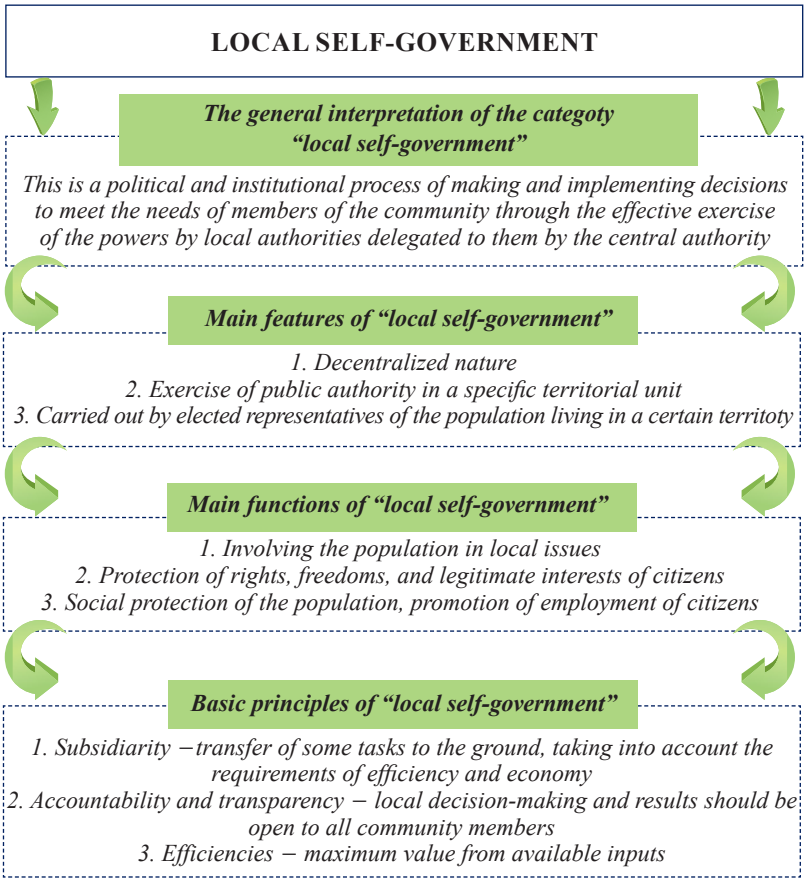

Figure 1. *Structuring the definitions of the category "local self-government"*
Source: *developed by the author based on [1-3]*

Thus, local self-government will be considered as a separate organizational and legal mechanism of public administration at the regional level of the country, the key elements of which are a united community of people (territorial community) and local self-government bodies formed by this society under the procedure established by the legislation of Ukraine, and functioning based on adaptive management in objectively existing political and socio-economic needs and challenges, which leads to the urgent need for its constant improvement through the introduction of innovative approaches to the management of this mechanism.

RESULTS AND DISCUSSION

The key element of the above definition is the representation of local self-government as an organizational and legal mechanism, which is a complex system of related political, legal and organizational and managerial measures and resources by which the relevant modern methods, techniques, and technologies of public administration are introduced into the activities of self-government bodies and their effective and timely practical implementation is ensured at all stages of this implementation. Thus, it is possible to investigate the general properties and features by which the mechanism should be justified and characterized during its development:

– is a complex system, that is, all its structural elements are in close mutual connection and interaction, which allows the mechanism to be not a chaotic cluster of elements, but a structured set of interconnected resources that complement, develop, cause one another. This will ensure an integrated and consistent approach to the objectives and goals [6];

– the presence of a public-power nature – this means

that public authorities that form the political and organizational-legal aspects of the mechanism and are focused on solving problematic issues of the general public are vested with the powers to form the mechanism and ensure its effective functioning;

– must have a legal form – the development takes place within the legal framework of the state, but it should be noted that most of the elements of the mechanism for introducing innovative approaches to the activities of local governments are not exclusively legal, although they are implemented against the background of general legal influence. Taking into account the above characteristics and modern needs, it is possible to build an organizational and legal mechanism for introducing innovative approaches to the activities of local governments (Fig. 2).

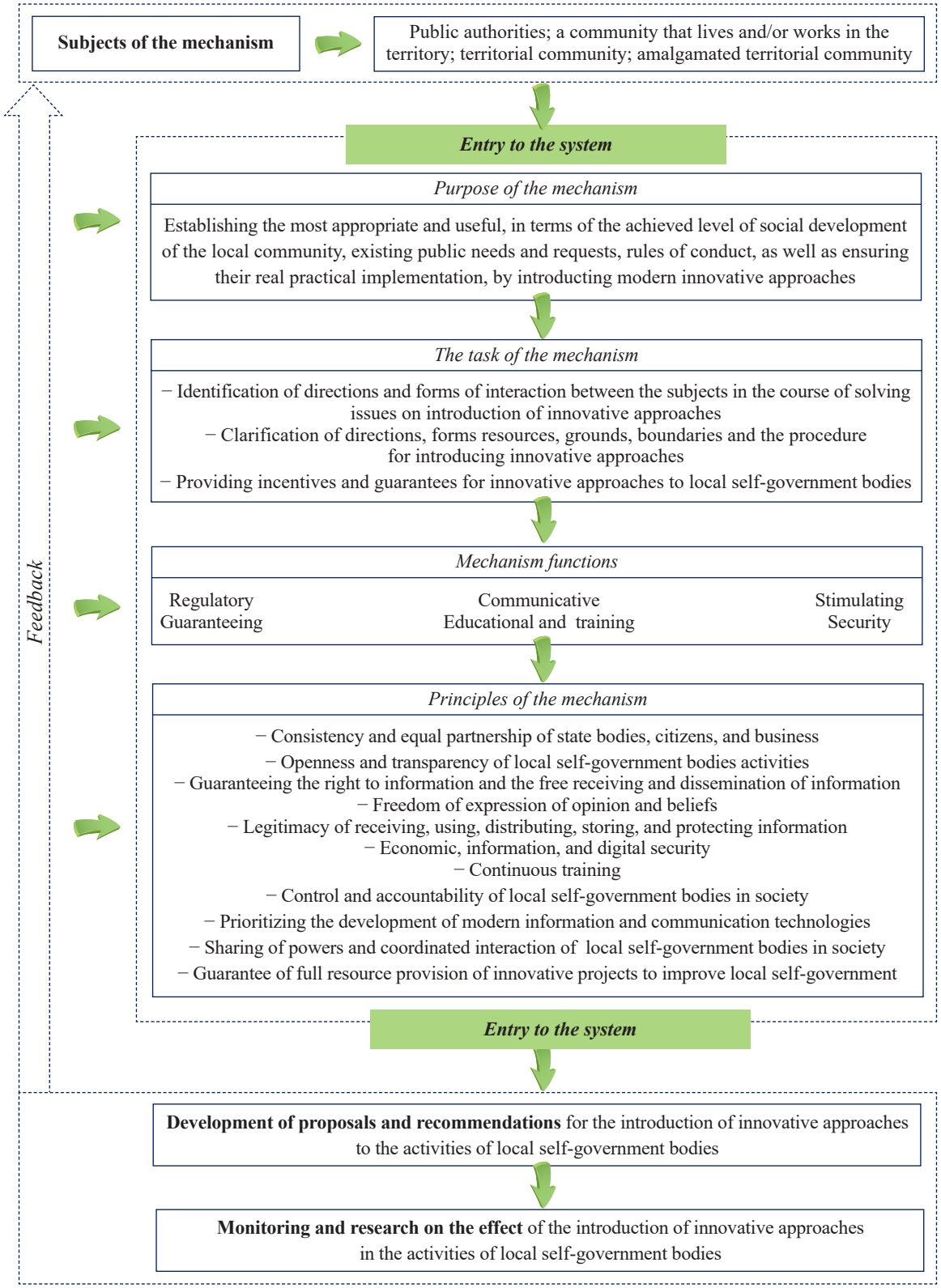

Figure 2. *Organizational and legal mechanism of introducing innovative approaches to the activities of local self-government bodies*

Source: *developed by the author based on [7-10]*

Figure 2 clearly demonstrates that the organizational and legal mechanism for introducing innovative approaches to the activities of local self-government can be presented as a complex phenomenon, which includes political-legal, organizational-managerial, financial-economic, scientific-technical, and other resources and measures. The effective and efficient functioning of the developed mechanism is a necessary and unconditional guarantee of the full and effective implementation of innovative approaches, the control of them, and the study of the effect of their impact on the local self-government system. At the exit of the complex system, which is the mechanism developed on Figure 2, the key element is the development of proposals and recommendations for the introduction of innovative approaches to the activities of local governments. Within the framework of this article, innovative approaches to the implementation of the system of provision of "electronic" public services and reengineering of administrative and management processes used in the activities of local governments will be investigated.

The introduction of innovative mechanisms for the provision of public services by local self-governments takes place against the background of the informatization of the life of society, as well as against the background of the integration of Ukraine into the European Union. The main goal of this process is to ensure that the needs of each member of the society are fully met and that the necessary conditions are created to increase the efficiency, transparency and openness of local authorities using innovative approaches and technologies. In turn, this requires the introduction of effective mechanisms for the provision of "electronic" public services by justifying and applying appropriate scientific and methodological tools based on the use of innovative information and communication technologies. In this direction, the first steps were taken towards the opening of Centres for the Delivery of Administrative Services and the creation of the system of the Unified State Portal of Administrative Services.

However, to date, there are many problems associated with the effective functioning of these institutions, namely: a number of centers do not have their own website; provision of irrelevant and contradictory information by the centres; insufficient material and technical base (especially in small territorial entities); poor and slow delivery of public services; insufficient indicators and criteria for monitoring the level of satisfaction of individuals and legal entities in public services; mainly lack of feedback from users of administrative services; the inability of the centres to provide separate public services (e.g. services of the state geodesy, cartography and cadastre service of Ukraine); insufficient number of centres in large cities, etc. Therefore, in order to solve the above problems, it is useful to develop the following innovative directions for improving the mechanisms for the provision of "electronic" public services by local governments of Ukraine (Fig. 3).

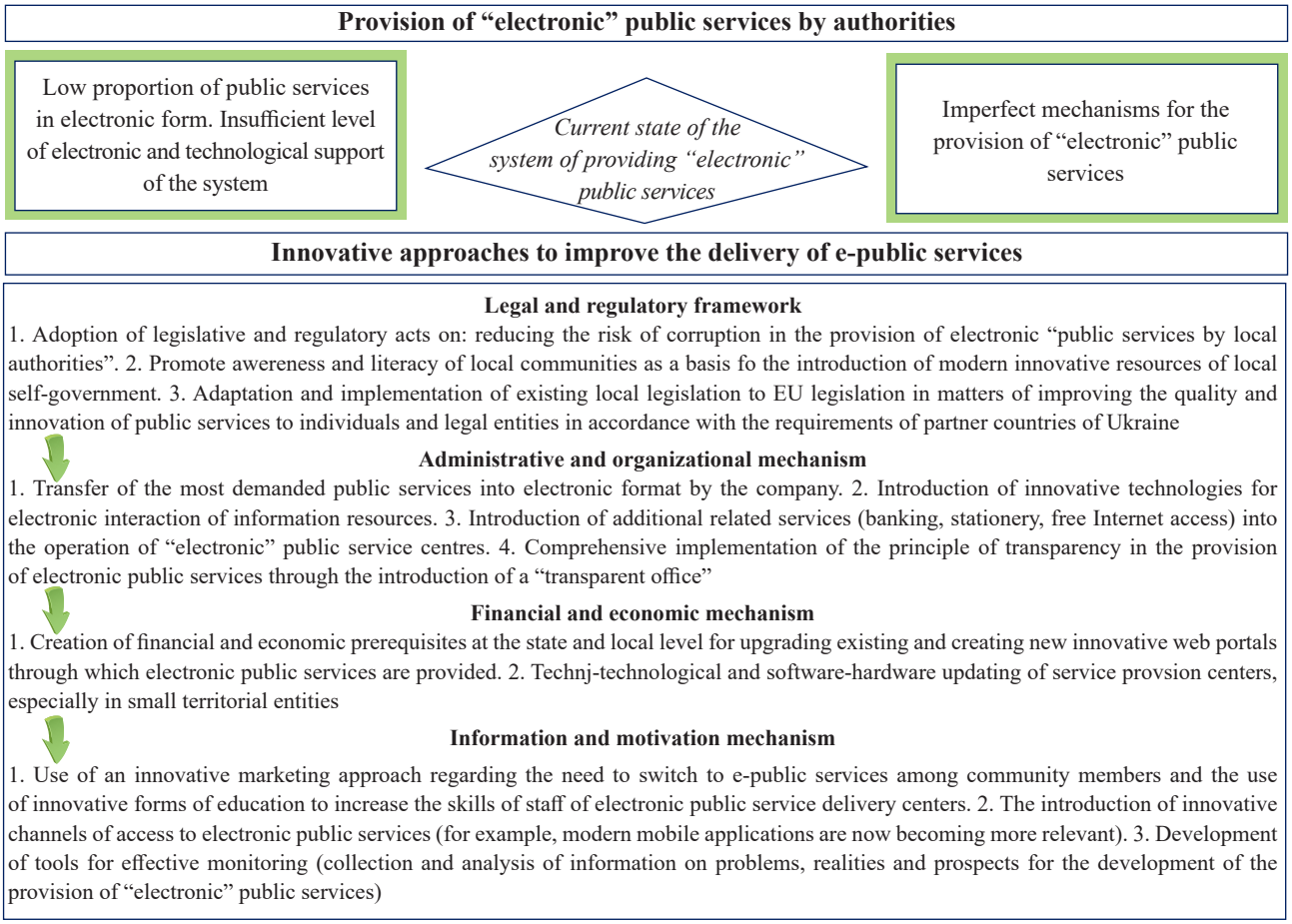

***Figure 3**. Innovative approaches to improve mechanisms for the provision of "electronic" public services by local authorities*
***Source**: developed by the author based on [11-14]*

Thus, the main result of the implementation of innovative approaches to improve the mechanisms for the provision of "electronic" public services by local authorities in Ukraine (Fig. 3) should be an improvement in the efficiency and quality of public administration, after all, the transformation of public services into electronic format will contribute to their optimization, strengthening processes of interaction between authorities, improving electronic interaction of state and local registries, which will reduce the "paper" document flow, free the time of civil servants to perform other functions, reduce financial costs and develop effective mechanisms to combat "bureaucracy on the ground". It should be mentioned that in foreign and Ukrainian practice it is also noted that one of the main innovative methods and tools for optimizing the activities of local self-government bodies is reengineering, which is aimed at introducing fundamental changes in the activities of these bodies in order to increase the socio-economic level and well-being of citizens and ensure the sustainable development of territorial communities [16]. With the help of reengineering, it is possible to evaluate and compare management activities with the strategic and tactical goals of the local government. Thus, a comprehensive rationale for the use of reengineering as an innovative tool for improving administrative and management processes, on the rational organization of which the final results of the activities of local governments, the development of society and the well-being of its members depend, becomes increasingly important. We will develop a general methodology for the reengineering of administrative and management processes of local governments in the form of stages and phases of its implementation in Table 2.

***Table 2**. Stages and phases of reengineering of activities of administrative and management processes of local self-government bodies*

No.	Reengineering phases	Reengineering stages
1	**2**	**3**
1.	***Phase 1***. Preparatory and organizational	*Stage 1*. Collection and analysis of documentation regulating the activities of local self-government bodies. *Stage 2*. Selection of the primary list of functions from the available set of documents *Stage 3*. Development of a list of functions of local self-government bodies, which establishes the correspondence between the functions of the body and the results of its activities. The result should be clear and visible information in the following sequence: action, result, recipient. *Stage 4*. Structuring the functions of local authorities by individual types (informational and analytical, permitting, registration, etc.). The end result of the function is a material and/or information product (decision, regulation, etc.) or a public service
2	***Phase 2***. Optimization of functions and processes with horizontal reengineering	***Sub-stage 1***: Structural analysis of functions/processes. *Stage 1*. Determining the current allocation of responsibility for the implementation of the process and functions by local self-government bodies. *Stage 2*. Decomposition of functions into a list of component processes in the form of detailed information related to the execution of the process. *Stage 3*. Development of a model of activity of local self-government bodies based on existing administrative and management processes in the form of a structural and logical scheme of the process ***Sub-stage 2***: Determination of optimization directions. *Stage 1*. Compliance of local self-government bodies subdivisions "horizontally" is established. *Stage 2*. Determination of the list of administrative and management processes carried out within the limits of the authorities established for local self-government bodies. *Stage 3*. Development of a scheme of administrative and management processes of local self-government bodies, which allows assessing the impact and consistency of processes. *Stage 4*. Selection of processes by determining the real impact on them by local self-government bodies. *Stage 5*. Assessment of the need for selected processes. *Stage 6*. Identifying "the weak points" of each process and identifying possible options for its restructuring (optimization). *Stage 7*. Identifying deficiencies and identifying key areas and objectives of process engineering and reengineering
3	***Phase 3***. Vertical reengineering for the introduction of innovative decision-making processes and the activities of local self-government bodies	*Stage 1*. Exclusion of functions and processes that cannot be executed are redundant or should be outsourced. *Stage 2*. Grouping of various activities of local self-government bodies regarding the powers granted to them. *Stage 3*. Function redundancy check. *Stage 4*. Checking for activities of local self-government bodies that are not related to the exercise of power. *Stage 5*. Review of the impact of relocating of functions not related to the exercise of power to outsource. *Stage 6*. Elimination of duplicate functions, if they occur

***Source**: [16; 17]*

Thus, in the process of reengineering the activities of administrative and management processes of local governments (Table 2) an optimal control system is built according to modern criteria, as well as conditions are laid for the formation of universal and effective mechanisms for further self-improvement since in terms of constant changes in environmental conditions, feedback is needed with the existing transformations of the control object so that after a certain period of time there are no needs for repetition (duplication) of the process. Proposals and recommendations for the introduction of innovative approaches to the activities of local self-government bodies are not limited to those given in the article, which is, in fact, key at the current stage. The continuous development of the local government system does not allow the development of sustainable types of innovative approaches to solve problems of local self-government "forever," but requires the constant monitoring of foreign experience of advanced countries and the constant development of new and progressive innovative mechanisms that will continue to introduce decentralization reform and the creation of strong and effective local authorities.

CONCLUSIONS

The presented scientific study is devoted to solving the important problem of improving the existing methods and resources of activity used in the activities of local self-government bodies through the introduction of modern innovative approaches. Based on this, all the objectives and conclusions were achieved in the work, and proposals and recommendations were given, namely:

1. The definition of the concept of "local self-government" is summarized using the regulatory margin and considering this concept in the context of modern realities that this institution of management is constantly facing. It was concluded that local self-government should be considered as a separate organizational and legal mechanism of public administration at the regional level of the country, the key elements of which are the united community of people (territorial community) and local self-government bodies formed by this community under the procedure established by the legislation of Ukraine and which functions based on adaptive management in objectively existing political and socio-economic needs and challenges, which leads to the urgent need for its constant improvement through the introduction of innovative approaches to the management of this mechanism.

2. An organizational and legal mechanism for introducing innovative approaches to the activities of local self-government bodies has been developed, the effective and efficient functioning of which is a necessary and unconditional guarantee of the full and effective implementation of innovations, monitoring them and studying the effect of their impact on the local self-government system.

3. Innovative approaches have been formed and justified to improve the mechanisms for the provision of "electronic" public services by local self-government bodies and the conclusion has been made, that the main result of this process should be to improve the efficiency and quality of public administration, after all, the transformation of public services into electronic format will contribute to their optimization, strengthening the processes of interaction between authorities, improving the electronic interaction of state and local registries will reduce the "paper" document flow, free up time for civil servants to perform other functions, reduce financial costs and develop effective mechanisms to combat "bureaucracy on the ground".

4. A general methodology for reengineering the administrative and management processes of local self-hovernment bodies in the form of phases and stages of its implementation has been developed. It was concluded that in the process of reengineering the activities of administrative and managerial processes of local self-government bodies, an optimal management system is being built according to modern criteria, and conditions are laid for the formation of universal and effective mechanisms for further self-improvement, since under conditions of constant changes in ambient conditions it is necessary to feedback the existing transformations of the control object in such a way that after a certain period of time there is no need to repeat (duplicate) the process.

The results of the scientific study can serve as a basis for continuous self-improvement of the system of local self-government, the search for new innovative approaches and their implementation to meet the needs of society for high-quality and effective public services.

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Впровадження інноваційних підходів у діяльність органів місцевого самоврядування України

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Анотація. Стаття присвячена проблемам пошуку та впровадження сучасних інноваційних підходів до діяльності органів місцевого самоврядування України. Встановлено, що подолання проблем старих і неефективних моделей та методів управління, що не відповідають вимогам сучасних спільнот, можливе лише шляхом розробки якісного та ефективного теоретичного, методичного, організаційного й правового забезпечення процесу місцевого самоврядування. Узагальнено визначення поняття «місцеве самоврядування» за допомогою нормативої маржі та розглянуто це поняття в контексті сучасних реалій, з якими зараз постійно стикається інститут управління. Для потреб розв'язання викладених у статті проблем і проблем розроблення авторської інтерпретації категорії «місцеве самоврядування», розроблено організаційно-правовий механізм впровадження інноваційних підходів до діяльності органів місцевого самоврядування як основного елемента визначення категорії «місцеве самоврядування». Досліджено проблеми, що пов'язані з ефективним функціонуванням установ з надання «електронних» державних послуг. Розроблено та обґрунтовано інноваційні підходи до вдосконалення механізмів надання місцевою владою «електронних» державних послуг. Розроблено загальну методологію реінжинірингу адміністративно-управлінських процесів органів місцевого самоврядування у вигляді фаз та етапів її впровадження. Зроблено висновок, що безперервний розвиток системи місцевого самоврядування не дозволяє розробляти стійкі типи інноваційних підходів до вирішення проблемних сфер місцевого самоврядування «назавжди», а потребує постійного моніторингу іноземного досвіду передових країн та постійний розвиток нових і прогресивних інноваційних механізмів, що продовжать впровадження реформи децентралізації та створення потужних й ефективних органів місцевого самоврядування

Ключові слова: нові шляхи, муніципалітети, реінжиніринг, організаційно-правовий механізм, державна служба

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Male Infertility: Pathogenetic Significance of Oxidative Stress and Antioxidant Defence (Review)

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Abstract. The basis of the pathogenesis of male infertility is the processes of peroxide oxidation of biological substrates, especially lipids and proteins. By destroying the sperm membrane, toxic peroxidation products reduce its motility and ability to fertilize the egg, which is determined by a decrease in the number of motile sperm in the ejaculate. These changes lead to complete or partial male infertility. The authors of the review found that is accompanied by a damaging effect on the structural and functional activity of the gonads and is manifested, in particular, by an imbalance in the hormonal background of the male body. Similar effects are characteristic of an increase in the content of reactive Nitrogen species and its metabolites, which cause nitrosative stress, which is also the cause of male hypofertility and is inseparable from the state of oxidative stress. In scientific work it is determined that the accumulation of harmful peroxidation products leads to damage and destruction of sperm DNA, reduced activity of acrosomal enzymes and mitochondrial potential of sperm, reduced overall antioxidant activity. This makes it impossible for an adequate response of the body. Multi component antioxidant defense system resists stress. It is represented by enzymatic and non-enzymatic links, which can neutralize harmful radicals and peroxidation products. It contributes to the full manifestation of reproductive function. The presence of powerful antioxidant properties of catalase, superoxide dismutase, and enzymes of the thiol-disulfide system, which form the enzymatic system of antioxidant protection, as well as selenium, zinc, copper, other trace elements, retinol, tocopherol, ascorbic acid, and vitamins as parts of the non-enzymatic system is shown. The efficiency of registration is substantiated thin biochemical shift detectors or complex methods, such as total antioxidant status of sperm or sperm plasma, mitochondrial membrane potential, etc along with simple markers of oxidative stress, such as diene conjugates, malonic dialdehyde, and metabolites of the Nitrogen Oxide cycle. Given the leading role of oxidative stress in the development of male hypofertility, the prospect of further research is the search for modern means for correction, especially among substances with pronounced redox activity

Keywords: reproductive ability, lipoperoxidation, antioxidant enzymes, Nitrogen oxide cycle

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INTRODUCTION

The reproductive system of males depends on various factors. It is subject to many negative influences of the external and internal environment and, as a rule, is not able to respond adequately [1; 2]. The main link in the pathogenesis of pathologies of the reproductive system in males, causing a decrease in sperm quality, is considered to be the state of oxidative stress (OS) of their bodies [3]. Oxidative stress is an excessive increase in the processes of lipid peroxidation, proteins, etc. (increased synthesis and/or accumulation of oxygen radicals) against the background of low activity of antioxidant protection (AOP).

The role of reactive oxygen species (ROS) in spermatogenesis, germ cell function, and fertilization has been studied for over 80 years. Thus, we know that low concentrations of ROS are important for physiological processes in sperm, such as acrosomal response and interaction of sperm with oocytes, in return the high levels of ROS underlie the imbalance of the prooxidant-antioxidant system, causing OS, which is one of the most destructive factors affecting sperm function and reducing male reproductive potential [4-9].

Similar data exist on the relationship between high concentrations of Nitrogen Oxide and metabolites of its cycle, which are formed by increasing the synthesis of reactive Nitrogen species (RNS), with the state of the male reproductive system [10]. ROS/RNS in the body can play both a physiological role and have a negative impact on reproductive ability, causing stress, such as OS and nitrosative stress, accompanied by a decrease in the number of motile sperm, damage to their membranes and acrosomal enzymes, mitochondrial dysfunction of germ cells. The biochemical relationship between oxidative and nitrosative stress is inseparable and, as a rule, these processes take place in the body of animals in parallel [10-15].

Widely used in urological practice, the term male infertility states a complete inability to fertilize the oocyte, while in the practice of reproductive endocrinology and andrology the term hypofertility is used, i.e., reduction of male fertility, given the possibility of effective correction/treatment [16-18]. Increases in the content of ROS/RNS are found in natively obtained and epididymal sperm and sperm plasma of almost half of men with hypofertility, while observing different dynamics of the components of ROS [19; 20]. Thus, the study of this problem does not lose its relevance, and taking into account the results is a necessary condition for the development of effective means of correcting male hypofertility.

The study aimed at the analysis of professional literature sources regarding modern ideas about the importance of oxidative stress in the pathogenesis of male hypo-/infertility, as well as substantiation of the role of the antioxidant defense system in maintaining reproductive potential.

PATHOGENETIC SIGNIFICANCE OF OXIDATIVE STRESS IN MALE HYPOFERTILITY

The concept of oxidative stress and the role of reactive oxygen species

The results of many years of research by scientists from all over the world prove the need to assess the balance of the prooxidant-antioxidant system in various pathological states. OS is a condition characterized by an excess of ROS and/or by deficiency of antioxidants. OS is the leading cause of decreased reproductive capacity (hypofertility) and infertility in males. The destructive force of OS is damage to lipids, membrane proteins and organelles and cell DNA, as a result of which the cyclic cascade of redox reactions weakens the functions of sperm and the reproductive system in general (Fig. 1) [21].

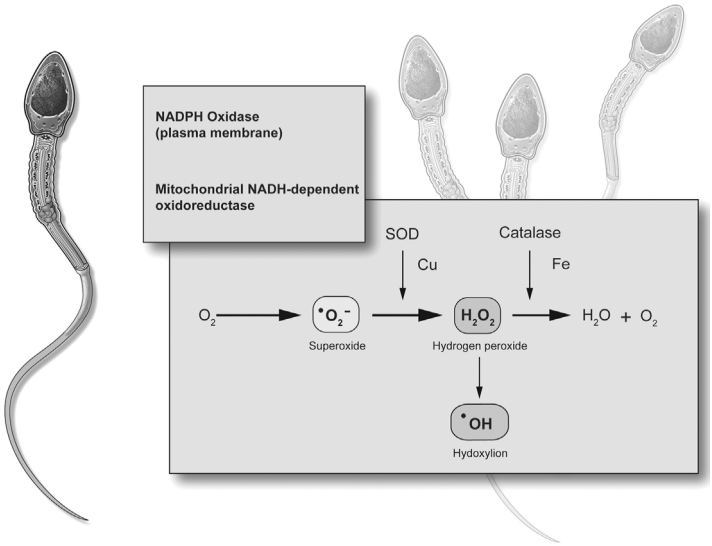

Figure 1. *Reactive oxygen species in sperm*

Source: *[21]*

Certainly oxidative damage to the genital system is found in various reproductive diseases with toxic poisoning, long-term use of drugs. For example, sulfur mustard, as a cytotoxic and chemical agent, damages tissues, including the reproductive system and causes male infertility on the background of OS [22]. OS is also considered to be the cause of male sperm hyperviscosity syndrome, and, at the same time, sperm hyperviscosity syndrome induces increased ROS synthesis, i.e. causes OS [23].

Also, current data suggest the involvement of OS as a central element contributing to hypofertility in males with varicocele, to which the testes respond by heat stress, ischemia, or the production of vasodilators such as Nitrogen Oxide [24; 25]. OS is also observed in prostatitis at the local and systemic level with a decrease in sperm quality mainly due to elevated concentrations of ROS [26; 27]. ROS are formed in sperm plasma from endogenous sources such as leukocytes or immature sperm and are physiologically necessary for sperm motility and oocyte fertilization. The effect of ROS on male fertility is regulated by an oxidative paradox, which is determined by a delicate balance between oxidative stress and antioxidant activity. With proper regulation, ROS ensure the effective functioning of the male reproductive system. On the contrary, with the increasing generation, a disproportionate number is formed, which causes a decrease in sperm reproductive function and is the cause of male hypofertility [28].

In general, with a small accumulation of ROS, the body can respond adequately and prevents the negative consequences of their impact. However, with the inferiority of diets, metabolic disorders, under the influence of various environmental pathogens, reveal an imbalance in the interaction of free radical oxides with scavenger substances. Such changes are the cause of most cases of idiomatic forms of infertility (Fig. 2) [21].

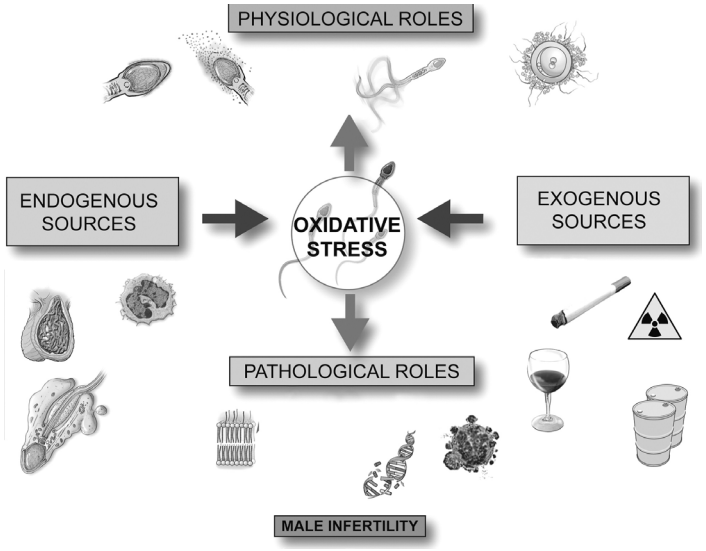

Figure 2. *Scheme of the physiological/pathological roles of reactive oxygen species and sources leading to increased production*

Source: *[21]*

The reasons for the development of OS are various: these are inflammatory processes in the genital system, including varicocele, nutritional deficiencies, obesity, metabolic syndrome, sexually transmitted infections (*Neisseria gonorrhoeae, Chlamydia trachomatis, Treponema palldum*, etc.), prostatitis, including bacterial genesis, mutations in microorganisms that lead to OS, viral infections (e.g., human immunodeficiency virus, hepatitis, etc.) [4; 29]. The development of OS is noted under the action of gamma radiation, which was found in experiments on rats of both sexes combined with a state of hemodynamic stress [30]. Factors contributing to the development of hypofertility in men include smoking and alcohol abuse, which contributes to lower sperm quality and sex hormone levels [31].

Particularly dangerous is the effect of organophosphorus compounds, such as dimethoate, which affects the reaction of OS in rat sperm *in vitro*, on the antioxidant protection of sperm [32]. Sperm DNA fragmentation due to impaired spermatogenesis, probably caused by OS, is observed in men with obesity, the influence of which in parents can adversely affect the reproductive and metabolic health of offspring [33].

Intensity of lipoperoxidation processes and reproductive potential

Numerous studies have shown that the decrease in reproductive potential is accompanied by an increase in the intensity of lipoperoxidation processes, for example, researchers at the Department of Obstetrics and Gynecology JIPMER, India, found statistically significant differences in the content of MDA in men with abnormal sperm parameters, and they had a reduced index of oxidative stress, compared with the group of men with normal

sperm counts [34]. This is due to the presence of large amounts of polyunsaturated fatty acids in mammalian sperm membranes, which makes them particularly sensitive to lipid peroxidation (LPO) [35]. This has been repeatedly proven experimentally – scientists at the University "Rovira i Virgili", Spain have created an experimental model of hypofertility of male rats, induced by sulfasalazine, with the introduction of which there is an increase in the content of substances reacting with thiobarbituric acid (TBARS), a decrease in the content of SOD and GSH in the testes and their appendages [36].

Determination of ROS concentration and LPO intensity in sperm and sperm plasma are used as a means of determining male fertility. In men with a decrease in sperm quality, there is an increase in the content of primary products of LPO – DC: while in sperm and sperm plasma the concentration of MDA also increases significantly [37; 38].

The mechanism of hypofertility of males under the influence of high concentrations of ROS

Sperm morphology is an important and complex characteristic of their fertilizing ability. It is shown that OS affects the morphology of sperm, causing the development of its abnormal forms, damage to membranes. Thus, the frequency of teratozoospermia may be directly related to excess ROS production; this shows that the assessment of sperm morphology is no less important criterion for assessing sperm quality, in addition to the activity and concentration of sperm [39]. OS in hypofertility causes in males a significant decrease in sperm motility, an increase in the percentage of morphological abnormalities, mainly the tail of sperm, with a significant decrease in the total antioxidant capacity of serum, the content of uric acid and albumins.

Thus, a decrease in the antioxidant capacity of blood serum, content of uric acid and albumin leads to the destruction of the sperm membrane, which, in turn, reduces the progressive motility of cells [40]. The negative effect of OS is realized by the action of high concentrations of ROS, which lead to oxidative damage to sperm membranes and DNA of male gametes as a result of gene mutations and by direct destruction of the DNA backbone, mitochondrial dysfunction and apoptotic cell death [41]. OS causes damage to both mitochondrial and nuclear DNA, while affecting the sperm epigenome, which leads to infertility, recurrent miscarriages, the negative course of pregnancy and increased morbidity of offspring [42].

It is believed that OS also affects normal embryonic development. Studying the phenomenon of OS sperm, researchers have identified the role of antioxidant protection in the male germline [43]. At the same time, sperm can't repair damage caused by OS due to limited AO potential. With the development of infertility on the background of OS, note a probable increase in the content of copper in serum and sperm plasma and the level of iron in sperm plasma, which indicates their direct participation in spermatogenesis and suggests that these ions act as mediators of oxidative damage [44].

Our research has proven the leading role of OS in reducing the reproductive capacity of boars. Thus, we have noted the intensification of LPO with a decrease in the quality of boar sperm. It is confirmed by the reliable growth of primary – DC and secondary – MDA products of lipoperoxidation [2]. Data on the effect of ROS on the histohematological barriers of the male body were obtained. Thus, in the testes of mammals, the blood-testicular barrier, in contrast to the blood-encephalic and blood-ophthalmic barriers, consists of coexisting dense tissues and adhesions, however, these compounds must be opened (or disengaged) to adapt to migration of preleptoten and leptotene spermatocytes through the blood-testicular barrier during spermatogenesis while maintaining its integrity [45]. The temporary opening of the blood-testicular barrier, which promotes the movement of germ cells, is mediated through the effect of ROS, testosterone and cytokines on the kinetics of endocytosis and recirculation of integral membrane proteins [46]. It should be noted that such changes are also likely to be involved in the pathogenesis of male infertility.

Features of OS development in semen during cryopreservation and thawing

The widespread use of a variety of media for the selection, use, and storage of sperm of men with pronounced antioxidant capacity allows not only to preserve the reproductive potential of cells but also to investigate in a standardized medium with high AO dynamically or indirectly ROS production of sperm or other contaminating cells [47]. The ability to protect sperm from oxidative damage is particularly critical for the artificial insemination industry due to the increased synthesis of ROS by sperm during processing. Many studies have focused on reducing the fertility of boar sperm after cryopreservation and thawing due to an increased tendency to oxidative damage compared to other species, which is hindered by the use of antioxidants – GSH, SOD, vitamin E, etc. [48]. Increased ROS generation as a side effect of bull sperm cryopreservation leads to OS, protein degradation, DNA fragmentation, and cell death. To prevent this, the lycopene effect, which reduces ROS synthesis in semen and promotes the preservation of acrosomal response and mitochondrial potential of sperm, has been studied [49].

NITROGEN OXIDE CYCLE AND ITS INFLUENCE ON SPERMATOGENESIS AND SPERM QUALITY

Nitrogen oxide (NO) has a critical role in the functioning of the male reproductive system, represented by NO itself, its metabolites, and a specific enzyme – NO synthase (NOS) and its isoforms. NO at low concentrations plays a leading role in the signaling pathways regulation,

regulates smooth muscle tone, controls the permeability of the blood-testicular barrier, erectile function, etc. [10; 50]. ROS/RNS-mediated redox signaling is extremely important for sperm reproductive function [51]. At low concentrations, the metabolites of the Nitrogen Oxide cycle act as scavengers of oxygen radicals. NO is produced by NOS and plays an important role in reproduction from the brain to the genitals. Germ cells and leydig cells in the testes show stage-dependent nuclear and cytoplasmic endothelial and inducible NOS immunoreactivity. All three isoforms of NOS were localized on the nuclear membrane and cytoplasm of epithelial cells in all ducts, in the tail and cytoplasmic droplets of sperm [52]. The male gonad-specific subclass nNOS, known as TnNOS, has recently been identified as a fairly powerful source of NO. TnNOS is located exclusively in Leydig cells – this confirms the involvement of the Nitrogen Oxide cycle in the hormonal function of the testes. With increasing NO content it is involved in the formation of AFN – peroxynitrite (ONOO-), NO_2, $N2O_3$, nitroxyl ion, nitrosyl-containing compounds that cause nitrosative stress [10]. Recently, new scientific data have been obtained on the properties of NO in conditions close to mammalian biology. Thus, it is proved that NO is not oxidized and not reduced by one-electron processes, reacts with other free radicals at a rate close to limited diffusion, and autoxidation rate is a second order in NO concentration, hence slow under bioregulatory conditions [53]. A study of the role of inducible NOS in testicular dysfunction in varicocele revealed a predominant expression of iNOS in the cytoplasm of Leydig cells and only a small percentage of its expression in Sertoli cells. Because iNOS activity was likely to be higher in Leydig cells in rats with varicocele, iNOS activity may play a leading role in testicular dysfunction associated with varicocele in adolescence [54].

Influence of nitrogen oxide cycle metabolites on spermatogenesis and sperm quality

Experimental studies have shown that the decrease in sperm function in male rats caused by nicotine improves a decrease in NOS activity, while investigating the effectiveness of L-arginine to inhibit NOS, found a reduction in spermatotoxic effects through a mechanism that depends on circulating testosterone levels [55]. On the other hand, data on NO_x content in the sperm plasm of healthy and infertile men were obtained and no reliable data were obtained on the correlation between NO content and sperm quality [56]. Contradictory results of researchers can be explained by the difference in the methodology of work. Our research revealed a reliable increase in the number of stable metabolites of the NO cycle due to a decrease in the reproductive capacity of boars in OS, accompanied by deterioration in sperm quality, especially motility and number of motile sperm in the ejaculate [2].

ANTIOXIDANT PROTECTION AND ITS ROLE IN THE REPRODUCTIVE POTENTIAL OF MALES

Features of the components of the antioxidant defense system functioning and their role in the activity of the male reproductive system

Sperm are highly sensitive cells to high levels of ROS due to the limited antioxidant system present in these terminal cells. However, to achieve the unique goal of sperm, i. e. to transfer the parental genome to a mature oocyst during fertilization, it is necessary to ensure strict regulation of ROS levels. Thus, active antioxidant systems are critical for sperm function [57]. AO are compounds that inhibit the synthesis or neutralize the action of prooxidants, in particular ROS [40; 58]. In the normal physiological state, sperm plasma contains a mechanism of AO enzymes that are able to neutralize toxic ROS, as well as have a protective effect on sperm from any possible damage. AO such as vitamins E and C, carotenoids and carnitine, when ingested, are able to increase the AO potential of cells, and, in general, have a positive effect on spermatogenesis [59-62]. Sperm are protected from OS by the enzymes of the AO system, which regulates the concentration of ROS. Sperm plasma is saturated with various AO to protect sperm from OS – enzymatic AO (SOD, catalase, GSH redox cycle enzymes) and non-enzymatic (ascorbate, tocopherol, GSH, etc.) [63].

We proved a decrease in the activity of AO enzymes when reducing the reproductive capacity of boars in the OS. In particular, both SOD and CAT activity – enzymes of the first link AO and GSH-Px and GSH-Rd in the serum of boars with low sperm quality [64]. Despite the antioxidant activity of sperm plasma, testicular appendage, and sperm, OS damages DNA integrity and disrupts sperm function [65; 66]. That is why an important issue is the functioning of antioxidant protection in the male reproductive system. Extracellular SOD has been found in the testes in relatively large quantities compared with other male organs. When studying some rat tissues and cells using a reverse transcriptase and polymerase chain reaction, we have shown that germ cells express approximately one-third of the expression of Sertoli cells. We can be suggesting that both cell types have the mechanisms necessary to protect against radicals. These studies demonstrate the importance of the SOD molecule for the male reproductive system, which is regulated by germ [67]. Researchers have obtained conflicting data on the effectiveness of endogenous antioxidants in inhibiting the effects of ROS as a means of treating male hypofertility or as a means of adding to the culture medium in the distribution of sperm has low efficacy [68].

The level of antioxidants in sperm plasma plays an important role in the etiology of sperm dysfunction and is closely related to male hypofertility, and a decrease in their concentration or intake of substances necessary for their synthesis may be one of the causes of infertility [69; 70]. The thiol-disulfide system, the so-called

glutathione redox cycle, occupies a considerable place in the antioxidant protection system of the male body. Glutathione – the primary AO of the body helps to preserve other types of AO. Its presence is noted in male and female gametes but in different quantities [71]. The level of antioxidants in semen is very vulnerable and variable. For example, cryopreservation reduces sperm quality and activity of sperm AO, which under the action of lycopene and α-lipoic acid increase in the experiment on cashmere goat [72].

Clinical studies have shown a decrease in antioxidant protection in the sperm plasma of infertile men, which correlates with sperm quality. Thus, the observed reduced activity of G-6-PDH causes increased ROS synthesis, which is confirmed by the reliably higher content of MDA. There is a decrease in the amount of GSH and SOD, which leads to the fragility of sperm membranes under the action of ROS and affects the ion exchange required for normal motility. Thus, the experiment showed a direct relationship between the antioxidant system with asthenospermia and the clinical parameters of sperm [73].

Other groups of researchers obtained similar results [74]. A group of scientists showed the effectiveness of selenium and vitamin E supplements to improve the quality of dog sperm and increase the antioxidant status of sperm, as evidenced by increased GP activity and overall antioxidant capacity of cells, which leads to normalization of sperm quality in animals with hypofertility [75]. Also, researchers obtained data on the negative impact of maternal obesity in rats on the antioxidant defense system of the testes in male offspring. The use of high-fat diets during fetal development causes phenotypic changes such as imbalance of lipid synthesis and increased OS, causing changes in male fertility, which, in turn, may explain the decrease in their reproductive capacity [76].

Markers of male reproductive potential: ROS and their metabolites, total antioxidant capacity, mitochondrial potential

Increased ROS production and DNA fragmentation are observed in infertile patients compared to the fertile group. Thus, changes in ROS synthesis may be associated with idiopathic infertility, i. e. assessment of the content of OS markers is a reliable prognostic criterion for male reproductive potential [77]. Spermatozoa are very vulnerable to ROS due to their inherent shortcomings of intracellular antioxidant enzymatic protection. Thus the body's overall antioxidant capacity becomes more vital for sperm protection [40]. There is an urgent need for reliable diagnostic tests that would allow you to quickly and comprehensively determine the state of the OS. The methods available to researchers to establish the OS allow determining only some components or their related substances [21]. Mitochondrial membrane potential indicates sperm functionality, which is determined using specific fluorescent markers [78]. Sperm DNA damage by OS is investigated in different ways. During spermiogenesis, which is the last stage of sperm maturation, there is a stage of remodeling of the sperm plasma membrane, which enhances the regulation of membrane receptors promoting the binding of the pellucid membrane, such as hyaluronic acid receptors. It was noted that spermatozoa selected using hyaluronic acid as a selector, show such characteristics as minimal DNA fragmentation, normal morphology and reduced frequency of chromosomal aneuploidies, which indicates the effectiveness of using the analysis of hyaluronic acid binding as a method of selecting mature, functionally active spermatozoa [79]. Practical reproductive medicine uses the indicator of DNA fragmentation as a reliable indicator of fertility, which is more specific than conventional indicators of sperm quality [80]. Testing for ROS content and antioxidant capacity could potentially provide additional prognostic information to standard laboratory tests for male infertility [81]. The overall antioxidant capacity of male sperm is also studied under conditions of different environments with a high content of AO [47]. As a biochemical predictor of male fertility, the effectiveness of the total antioxidant status use has been proven by determining this indicator in sperm plasma using the Randox kit in groups of healthy and infertile (with different types of reduced sperm quality) men in Pakistan. It proves reliably higher antioxidant protection levels in fertile men and the presence of a positive correlation with the concentration, motility of sperm, and content of cells with normal morphology [82; 83].

CONCLUSIONS

Oxidative stress is a leading pathogenetic mechanism of hypofertility (reduced reproductive capacity) of males, which due to the accumulation of toxic peroxidation products has a detrimental effect on the reproductive system by reducing the mitochondrial potential of sperm, and, consequently, their motility, damage to acrosomal fertilization. The vast majority of authors agree that this occurs under prolonged exposure to negative factors, as a result of which the antioxidant defense system loses the ability to adequately respond to the intensification of peroxidation processes and requires pharmacological correction. In this case, the definition of markers of OS and the dynamics of AOP should be used along with commonly used methods of testing male fertility, such as assessment of sperm quality and hormonal background. A promising area of research, in our opinion, is the search and scientific justification of safe and effective means for correcting male hypofertility under oxidative stress.

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Неплідність самців: патогенетичне значення оксидативного стресу та антиоксидантного захисту (огляд)

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Анотація. Основою патогенезу неплідності самців є процеси пероксидного окиснення біологічних субстратів, особливо, ліпідів і протеїнів. Руйнуючи оболонку спермія токсичні продукти пероксидації знижують його рухливість і здатність до запліднення яйцеклітини, що визначається зменшенням кількості рухливих сперміїв у еякуляті. Ці зміни призводять до виникнення повного або часткового чоловічого безпліддя. Авторами статті було встановлено, що це супроводжується ушкоджуючою дією на структурну і функціональну активність статевих залоз і проявляється, зокрема, дисбалансом у гормональному фоні організму самця. Аналогічними ефектами характеризується підвищення вмісту активних форм Нітрогену й метаболітів його циклу, що викликають нітрозивний стрес, який також є причиною гіпофертильності самців і перебігає нерозривно зі станом оксидативного стресу. У науковій роботі визначено, що накопичення шкідливих продуктів пероксидації призводить до ушкодження та руйнування ДНК сперміїв, зменшення активності акросомальних ензимів і мітохондріального потенціалу сперміїв, зниження загальної антиоксидантної активності, що унеможливлює адекватну відповідь організму. Стресовим станам протистоїть багатокомпонентна антиоксидантна захисна система, що представлена ензиматичною і неензиматичною ланками, здатна, до певної міри, знешкоджувати шкідливі радикали і продукти пероксидації, сприяючи повноцінному прояву репродуктивної функції. Показано наявність потужних антиоксидантних властивостей каталази, супероксиддисмутази і ензимів тіол-дисульфідної системи, що формують ензиматичну систему антиоксидантного захисту, та, Селену, Цинку, Купруму, інших мікроелементів, ретинолу, токоферолу, аскорбінової кислоти та вітаміноподібних речовин, як ланок неензиматичної системи. Обгрунтовано ефективність засобів реєстрації тонких біохімічних зсувів або комплексних методів – визначення загального антиоксидантного статусу сперміїв або спермальної плазми, потенціалу мітохондріальної мембрани, тощо поряд із простими маркерами оксидативного стресу, такими як дієнові кон'югати, малоновий діальдегід і метаболіти циклу Нітрогену оксиду. З огляду на провідну роль оксидативного стресу у розвитку гіпофертильності самців перспективою подальших досліджень є пошук сучасних засобів корекції, особливо серед речовин з вираженою редокс-активністю

Ключові слова: відтворна здатність, ліпопероксидація, антиоксидантні ензими, цикл Нітрогену оксиду

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