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Productivity and Quality of Broiler Chicken Meat Using New Triazolin Compounds

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Abstract. In providing the population with high-quality food products, a special place is given to poultry meat production. The purpose of this study was to investigate the effect of triazoline compounds on the productivity and haematological parameters of broiler chickens. The study was conducted in 2021-2022 at the Odesa State Agrarian University in vivarium and analytical laboratories. 1,2,4-triazole derivatives synthesised at the Zaporizhzhia State Medical University were used for the study: GKPF-109 – Morpholin-4-ium-2-((4-amino-5-(3-methyl-pyrazol-5-yl)-1,2,4-triazol-3-yl)thio)acetate; ASP-34 – sodium 2-((4-amino-5-(thiophen-2-ylmethyl)-4H-1,2,4-triazol-3-yl)thio)acetate. The dynamics of poultry growth was determined by individual weighing, followed by determination of absolute and average daily live weight gains. Poultry feeding was carried out according to species and age periods per the existing norms. Haematological, immunological, and biochemical studies were performed according to the following methods. Tasting evaluation of meat and broth was carried out according to a 5-point system. Broths were evaluated according to 4 indicators – taste, smell, colour, transparency, each of them according to a 5-point system. The analysis of total weight data in the groups indicates the highest gross gain in live weight in the group of 36-day-old chickens that received GKPF-109 from 10 days of age, which is 14,966 g in 26 days of the experiment. The preservation of broiler chickens during the experimental period was 96% in the experimental groups, and 94% in the control group. Analysing the above, it can be concluded that adding research compounds of the triazoline series to drinking water increases haematopoiesis, has anti-inflammatory and hepatoprotective effects. Evaluation of the quality of meat of broiler chickens and broth at the end of the experiment does not allow claiming a decrease in their aroma and taste qualities, which indicates the absence of a negative effect of the research compounds of the triazoline series and the methods of their application on the organoleptic parameters of the meat

Keywords: 1,2,4-triazole derivatives, meat productivity of broilers, poultry carcasses, growth, mass

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INTRODUCTION

The most important branch of animal husbandry, which provides the population with complete food products, is industrial poultry farming. The main indicators that determine the efficiency of the operation of this industry are the productivity, preservation of the poultry population, and the quality of the obtained products. Obtaining high-quality and safe poultry products directly depends on several biotic (De Boeck *et al.,* 2015; Paliy *et al.,* 2018) and abiotic (Mesquita *et al.,* 2021; Orobchenko *et al.,* 2022) environmental factors of keeping productive livestock. Therewith, preserving the health of poultry directly affects the yield of finished products, its cost price, and thus determines the economic efficiency of production (Mohammed *et al.,* 2021). It has been proven that the basis of poultry health and the successful realisation of its genetic potential is the proper functioning of the immune system (Song *et al.,* 2021). It is undeniable that vaccination is the main veterinary preventive measure necessary to prevent the occurrence and spread of infectious diseases (Hautefeuille *et al.,* 2020; Ike *et al.,* 2021). Along with vaccines, several immunomodulators and immunostimulants are used to increase viability, resistance to stress in poultry, as well as to ensure its high productivity (Krishan *et al.,* 2015; Hasted *et al.,* 2021).

Immunomodulators (IMDs) are drugs of various origins that can correct the body's immune system and increase its natural resistance. The vital property of IMDs is that they do not affect the normally functioning immune system (Al-Khalifa, 2016). The results of experimental studies and production tests allow recommending immunomodulators for introduction into the practice of industrial poultry farming, which is economically profitable and contributes to a substantial increase in the qualitative and quantitative characteristics of the resulting poultry products (Ghosh *et al.,* 2016; Rehman *et al.,* 2017). Despite the multitude of proposed immunomodulatory drugs for commercial poultry farming, their safety, impact on poultry productivity and product quality must be considered when using them (Sunder *et al.,* 2008; Arif *et al.*, 2019). It is necessary to give preference to those immunomodulatory drugs that can not only normalise the functional state of the immune system, but also stimulate the growth and development of poultry, increase its productivity indicators (Avango *et al.,* 2016). Almost any immunomodulatory drug has a maximum allowable dose and if it is exceeded, immunosuppression can be obtained instead of the expected positive effect (Bascones-Martinez *et al.,* 2014).

Currently, such immunomodulating drugs as Fosprenil and Gamavit are used in poultry farming. There is evidence that administering these drugs with water to broiler chickens can increase the productivity of poultry (Sanin *et al.,* 2011). An increase in immune protection of broiler chickens was established when copper nanoparticles were introduced into drinking water (Yang *et al.,* 2011; Ognik *et al.,* 2018). The influence of arginine on productivity and immunity of broilers was studied. Thus, with an increase in the content of arginine in the feed on Day 22, serum concentrations of antibody titres to Newcastle disease improved (Xu *et al.,* 2018). Scientific research conducted by Shyma K. Latheef *et al.* (2017) indicate the use of herbal preparations for prevention and stimulate the immune system of poultry under vaccination against infectious diseases. Among the feed additives that have gained popularity in poultry farming after the ban on antibiotic stimulants are probiotics. They are one of the most versatile feed additives and are easily combined with other additives. Probiotics have many benefits, including stimulating the development of macroorganism microflora and immunomodulating it (Krysiak *et al.,* 2021; Jha *et al.,* 2020).

One of the most effective methods of strengthening the body's immunity is balanced feeding. Lack of any nutrients adversely affects the immune system and increases the sensitivity of poultry to infectious diseases (Fritts *et al.,* 2004; Nosrati *et al.,* 2017; Schulze Brend *et al.,* 2020). Lack of substances such as linoleic acid, vitamin A, E, iron, selenium, and arginine has been proven to have a destructive effect on the immune system of poultry (Gilbert, 2018; Lin *et al.,* 2020), phosphorus and calcium (Hofmann *et al.,* 2021).

Modern crosses of productive poultry are more susceptible to various infections and metabolic diseases and show a high mortality rate. As a result, interest in the use of feed additives with immunomodulatory properties for use in commercial poultry farming has grown recently (Swiatkiewicz *et al.,* 2014). However, the effectiveness of using modern immunomodulators is still understudied. Today, the issues of establishing rational doses and modes of use of the most effective immunomodulatory drugs in poultry farming remain relevant. *The purpose of this study* was to improve technological methods for increasing the productivity of broilers with triazoline derivatives.

MATERIALS AND METHODS

The study was conducted during 2021-2022. Laboratory tests were carried out in the vivarium and analytical laboratories of the Odesa State Agrarian University, where 30 heads of broiler chickens were raised. Several 1,2,4-triazole derivatives synthesised at the Zaporizhzhia State Medical University were studied:

GKPF-109 – Morpholin-4-ium-2-((4-amino-5-(3-methyl-pyrazol-5-yl)-1,2,4-triazol-3-yl) thio) acetate (Fig. 1).

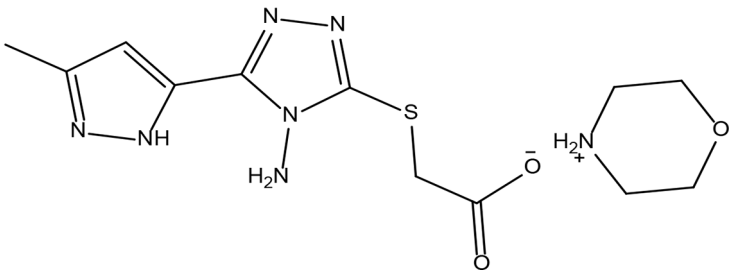

***Figure 1**. Chemical formula of GKPF-109*

***Note**: Chemical formula: $C_{12}H_{17}N_7O_3S$*
Molecular weight: 339.37
Calculated: C, 42.47%; H, 5.05%; N, 28.89%; S, 9.45%
Found: C, 42.36%; H, 5.04%; N, 28.97%; S, 9.47%

The synthesised compound is a white crystalline substance that is soluble in water, partially in alcohol, insoluble in diethyl ether, ethyl acetate.

ASP-34 – sodium 2-((4-amino-5-(thiophen-2-ylmethyl)-4H-1,2,4-triazol-3-yl)thio)acetate (Fig. 2).

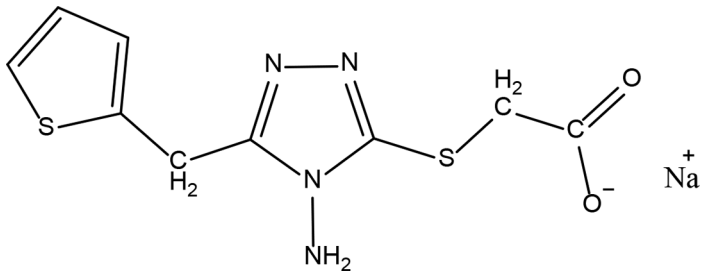

***Figure 2**. Chemical formula of ASP-34*

***Note**: Chemical Formula: $C_9H_9N_4NaO_2S_2$*
Molecular Weight: 292.31
Calculated: C, 36.98%; H, 3.10%; N, 19.17%; S, 21.94%.
Found: C, 37.14%; H, 3.11%; N, 19.15%; S, 21.90%.
The synthesised compound is a light-yellow crystalline powder

In the infrared spectrum, the test compounds have absorption bands of –C=N-groups at 1,630-1,610 cm^{-1}, –CH2-groups at 2,915-2,940 cm^{-1}, symmetric (1,388 cm^{-1}) and asymmetric (1,569 cm^{-1}) fluctuations of the –COO– group.

Administration of drugs with water is one of the most frequently used technological methods of administration of various medicinal substances and vaccines in poultry farming (Krysiak *et al.,* 2021).

The main purpose of this study was to investigate the new derivative compounds of the triazoline series on the productive qualities of broiler chickens. For this purpose, day-old birds were selected from which three experimental groups were formed: control (I) and experimental (II; III), 10 heads each. The young poultry was selected considering the following parameters: breed, age, live weight.

Triazoline compounds ASP-34 and GKPF-109 were added to the main diet of the control group every day, starting from the age of one day, in a dose of 0.5 ml per 1 liter of water. The dose of the drug ensured a water pH value of 4.5. Experimental drugs were given to experimental chickens from the 10th to the 14th day of rearing.

The experimental poultry was fed equally according to age periods (Leeson & Zubair, 1997). Protein nutritional value of starter feed of broiler chickens in 0-15 days was 21-23%, growth feed in the period of fattening from 16 to 30 days – 19-21%, finishing feed (31-38 days) – 18-20% and finisher (39-42 days) – 17-19%. The poultry was kept in standard cage equipment. Zoohygienic parameters (floor area and feeding front, lighting, ammonia level, humidity, air movement speed, etc.) corresponded to the regulations in force in poultry farming (Soliman *et al.*, 2017; Zabir *et al.,* 2021).

Broilers were weighed on Domotec electronic scales in the morning before feeding. Livestock conservation was determined by daily accounting. The effect of compounds of the triazoline series on the body of broiler chickens was investigated by haematological and immunological

indicators of blood. Blood collection for research was carried out in compliance with the rules of asepsis and antiseptics from the wing with heparin and trilon, and to obtain serum, blood was collected without the use of an anticoagulant.

The number of erythrocytes was measured in the Goryaev chamber. A drop of diluted blood was taken to fill the Goryaev counting chamber and after sedimentation in the chamber the cells were counted under a microscope. Number of red blood cells in 1 mm^3 of blood was calculated according to the following formula (1) (Sadovnikov *et al.,* 2009):

$$X = a \times 4{,}000 \times c \div b \quad (1)$$

where X is the number of red blood cells in 1 mm^3 blood; a is the number of red blood cells counted in 80 squares; b is the number of squares counted; c is the degree of blood dilution.

The number of platelets was counted in counting chambers on glass slides stained according to the Romanovsky-Giemse method. White blood cells were counted in 100 large squares with a total area of 4 mm^2. White blood cells and platelets were counted using a microscope. Platelet and white blood cell counts were calculated using the following formula (2) (Sadovnikov *et al.,* 2009):

$$X = \frac{A\text{x}4{,}000\text{x}20}{C} \quad (2)$$

where X is the total amount of blood per 1 mm^3; A are the counted cells; *1/4,000* is the capacity of one square; *20* is the breeding; C is the number of small squares counted.

To find the leukocyte formula, it was determined on blood smears stained according to the Romanovsky-Giems method. T and B lymphocytes were produced using a rosette formation reaction with ram erythrocytes (Sadovnikov *et al.,* 2009; Kanda *et al.,* 2020).

Erythrocyte sedimentation rate (ESR) was determined according to the Panchenkov micromethod. In a capillary pipette, pre-washed with a solution of sodium citrate, this solution is drawn up to the mark "P" and introduced into test tubes measuring 10x1 cm. Then, with the same capillary, blood was collected 2 times to the "K" mark, and it was introduced into the same test tube each time. After mixing, it was sucked into the capillary to the "O" mark and then placed in the tripod. After 1 hour, the value of the remaining plasma column was calculated according to the distribution of the capillary pipette. The sedimentation rate was determined in 1 hour. (Burton *et al.,* 1966).

Circulating immune complexes were performed in the selective precipitation of antigen-antibody complexes in a 3.75% solution of polyethylene glycol (PEG) with subsequent photometric determination of the optical density of the precipitate. The phagocytic activity of neutrophils was expressed as a percentage of leukocytes involved in phagocytosis to the total number of neutrophil leukocytes counted. To find the opsonophagocytic reaction, the method of V.M. Berman and E.M. Slavskyi (1982) was applied, which included the following methodological techniques: 1) the phagocytic function of chicken blood cells was investigated in relation to the gram-positive St. Aureus test microbe. The phagocytic index characterised the intensity of phagocytosis. The average number of phagocytosed microbes was found per active leukocyte. The phagocytic index was calculated by dividing the number of phagocytosed bacteria by the number of active leukocytes (Wansbrough-Jones, 1979).

Slaughter yield is the ratio of slaughter mass to live weight, expressed as a percentage. It was determined by which parts of the body are included in the slaughter mass. In poultry, the slaughter weight depends on the features of the post-slaughter processing of the carcass: it is the highest in uneviscerated poultry, as it includes the mass of the bloodless and plucked carcass with fat, head, limbs, and internal organs; a half-eviscerated bird has a mass of carcass with fat, but no intestines; with complete evisceration, blood, feathers, fluff, and intestines are removed, as well as all internal organs, and even the head up to the second cervical vertebra, limbs up to the metatarsals and wings up to the elbow joint. In control slaughter, the slaughter and meat qualities of the bird were determined: mass of eviscerated carcasses; pectoral muscle, fat, slaughter output.

Appearance (smell, consistency, state of fat, quality of broth upon cooking meat) was evaluated visually. The pectoral and hip muscles were cut across the direction of the muscle fibres, and their condition was determined on the cut. Filter paper was used to determine muscle moisture. Muscle colour was determined visually. Organoleptic assessment of poultry meat was carried out. To determine the flavour of the broth, 70 g of muscle was cut out, crushed. To determine the transparency and smell of the broth, 20 g of the crushed sample was weighed, poured with distilled water to about 60 ml, mixed, covered with a watch glass, and then placed in a water bath. During heating, the smell of the broth was determined at the moment of the appearance of steam. Transparency was determined visually in a cylinder with a diameter of 20 mm. The aroma of the broth was determined in hot broth at 80-85°C. The degree of transparency was determined visually by pouring 20 ml of broth. Comparing the results of the organoleptic examination of the samples with the requirements of the standard, the results of the study were described, and a conclusion was drawn about the quality of the meat. Tasting evaluation of meat and broth was carried out according to a 5-point system, evaluating each of the indicators according to the scale of the degree of quality, expressed in points: 5 – excellent; 4 – good; 3 – satisfactory quality; 2 – poor quality; 1 – unsatisfactory quality. Tasting indicators of meat and broth were determined according to modern methods (Jung *et al.,* 2014; Liu *et al.,* 2021).

Experiments conducted on animals do not contradict the current legislation of Ukraine (Article 26 of the Law of Ukraine No. 5456-VI "On the Protection of Animals from Ill-Treatment" dated 10/16/2012) and "General Ethical Principles of Animal Experiments", adopted by the First National Congress on Bioethics (Kyiv, 2001) and International Bioethical Standards (materials of the IV European Convention for the protection of vertebrates used for experimental and other purposes, Strasbourg, 1985).

The obtained digital material was processed using variational statistics (Plokhinsky, 1970) using the Statsoft Statistica 7.0 software package (StatSoft Inc., USA). In this paper, the values under study were presented as a sample mean and standard error of the mean (M±m). The Student's t-test was used to determine the average values. During the statistical analysis, the achieved level of confidence (P) was calculated. In this case, the critical confidence level was assumed to be 0.05.

RESULTS AND DISCUSSION

Administering triazoline compounds from day 10 to day 14 increased the average daily gain of live weight in the group receiving ACP-34 by 2.6% and GKPF-109 – by 6.2% compared to the control. In the period from the 15th to the 22nd day of rearing, the highest average daily growth was recorded in the group receiving GKPF-109. Thus, the average daily increase in this group was higher than in the control group by 18%, and from the group that received TSA-34 – by 15.4%. A similar trend was observed in the period from 22 to 26 days of raising chickens.

A decrease in the average daily weight gain in chickens was registered in the period from 26 to 31 days in all experimental groups, while in the rearing period from 31 to 36 days, an increase in the average daily weight gain was detected in the group that received GKPF-109. In the group with GKPF-109, this indicator was higher by 30.8% compared to the control, and by 11.4% compared to the group receiving ASP-34 (Table 1).

***Table 1**. The dynamics of the increase in live weight of broiler chickens with the introduction of compounds of the triazoline series (M±m; n=10)*

Indicator	Age of chickens, days					
	10	15	22	26	31	36
			Control			
Total weight, g	2,120	4,201	7,330	9,796	12,504	14,821
Average sample weight, g	212.0±13.1	420.0±29.9	733.0±52.8	979.0±65.2	1,250.0±85.7	1,482.1±105.22
Average daily growth, g	–	41.6±4.6	52.1±0.5	58.75±12.8	54.16±6.01	46.34±7.39
			ASP-34			
Total weight, g	2,103	4,240	7,372	10,024	13,016	15,737
Average sample weight, g	210.0±6.4	424.0±7.7	737.0±21.8	1,002.0±28.9	1,301.0±33.1	1,573.7±40.1
Average daily growth, g	–	42.7±1.8	53.3±4.4	66.3±6.1	59.8±8.4	54.42±8.55
			GKPF-109			
Total weight, g	2,389	4,430	8,120	11,240	14,140	17,355
Average sample weight, g	238.0±12.2	443.0±18.09	812.0±25.1	1,124.0±28.9	1,414.0±33.3	1,735.5±33.23
Average daily growth, g	–	40.2±3.9	61.5±5.9	73.3±5.0	58.2±7.4	60.6±2.75

***Note**: there is no probability in relation to the control*

The analysis of the total weight data in the experimental groups indicates the highest gross increase in live weight in the group of chickens of 36 days of age, which received GKPF-109 from the age of 10 days, which is 17,355 g for 36 days of the experiment. In the research group that received ASP-34, the increase in live weight during the same period amounted to 15,737 g. In the control group of chickens, the gross increase in live weight was 14,821 g. In the group with ASP-34, the total live weight of chickens at 36 days was lower than the group of chickens that received GKPF-109 by 1,618 g (9.4%). The total live weight of chickens from the group with ASP-34, compared to the control group, was higher by 916 g (6.2%), and in the group with GKPF-109 – by 2,534 g (17.1%). The increase in the average live weight of chickens in the groups after drinking the drugs at the age of 15 days was unreliable.

The average weight of 22-day-old chickens differed from the control group and from the group with ASP-34. Thus, chickens that received GKPF-109 had the highest average live weight of 812.0±25.1 g, which is 16 g (2.0%) higher than their peers that received ASP-34. The difference between the group of chickens receiving GKPF-109 and the control group during this period was 79 g (8.5%).

At the age of 26 days, the average daily increase in live weight in chickens of the experimental groups, compared to the control group, was also higher by

2.3% – in the group with ASP-34, and by 14.8% – in the group with GKPF-109. Therewith, in the group of chickens treated with GKPF-109, this indicator was higher than in the groups of their peers.

Therefore, the use of compounds of the triazoline series under study during the fattening period of broiler chickens stimulated the increase in their live weight.

The preservation of broiler chickens during the experimental period was 96–100% in the experimental groups, and 94% in the control group (Table 2).

***Table 2**. Preservation of chickens in experimental and control groups, %*

Group	Number of chickens, heads	Number of dead, heads	Preservation, %
Control	10	3	94
ASP-34	10	2	96
GKPF-109	10	0	100

During the experiment, the death of broiler chickens was observed in the second week of keeping. When conducting a pathological autopsy, it was found that in both groups they had a lower body weight compared to their peers, and changes in the effect of compressive influence. When obtaining the research results, it is possible to say that adding compounds of the triazoline series to the diet of broiler chickens has a positive effect on their growth and development.

During the daily clinical examination of broiler chickens, it was observed that in the first weeks of the experiment, the body of the chickens was covered with yellow down in both experimental and control groups. Starting from the 8th day, the growth of feathers around the wings was noted, the broiler chickens were mobile and consumed food well, the down and feather cover was clean. During the examination of the excrements, it was noted that it had a soft grey-brown consistency with white streaks. On the 14th day, the growth of wing and tail feathers was noted. Examining the mucous membranes of the conjunctiva, it was established that it was shiny, smooth, light pink, the excrement was soft in consistency, grey-brown with a green tint.

On the 22nd day of the experiment, the body of the chickens was covered with feathers, except for the areas of the wings and abdomen. A decrease in appetite and thinning of faecal masses were noted in the chickens of the control group. The excrements were grey-green with gas bubbles. The feather cover in the cloaca area was contaminated with excrements.

Starting from the 29th day of the experiment, the chickens of the experimental groups, which were given compounds of the triazole series, were active and mobile. The feather cover covered the entire body, except for the chest area. A decrease in appetite was noted in the chickens of the control group. The feather cover around the cloaca was contaminated with thin grey-green excrements. On Day 36 of the experiment, the body of chickens of the experimental and control groups was completely covered with feathers. In some poultry of the control group, the feather cover in the cloaca area was contaminated with grey-brown excrements. Visible mucous membranes were smooth, moist, shiny, and grey-pink. A decrease in the motor activity of chickens was noted in the control and experimental groups that were given the compound of the triazoline series APS-34, in the group that was given GKPF-109, the survival of broiler chickens was observed at 100%. By the end of the experiment, the body of both intact and experimental chickens was evenly covered with feathers. The chickens of the experimental groups actively consumed feed and water. In some chickens of the control group, a decrease in appetite was observed, their feather cover around the cloaca was contaminated with thin grey-green faecal masses with gas bubbles. From the research, it can be concluded that when triazole compounds are added to the diet, they have a positive effect on the clinical condition of the chickens in the experimental groups compared to the control group. The chickens of the experimental groups were more mobile, with satisfactory feed intake and formed excrements. This indicates the beneficial effect of compounds of the triazoline series on digestive processes, especially in critical phases of development starting from the first week of life, transition from one diet to another and during the period of juvenile moulting.

Haematological analysis belongs to the methods that can contribute to the detection of some changes in the state of health and can be useful for the diagnosis of poultry diseases (Tables 3, 4). Haemoglobin is an essential component of blood. Its function is to transfer oxygen and nutrients from cells to tissues, ensuring the normal flow of energy processes in the body. An increase in the level of hAemoglobin was found, namely in the group of broilers that were given the ASP-34 compound. In the GKPF-109 group, according to the table data, a decrease in haemoglobin was observed. The results of the colour index of broilers observed in all experimental and control groups were less than one. An increase in erythrocytes and haemoglobin in the broilers of the research groups may indicate that triazole compounds stimulate the processes of erythropoiesis, do not have a harmful effect on the stability of hematopoiesis and constancy in the composition and total amount of blood.

***Table 3**. Haematological parameters of broiler blood (M±m; n=10)*

Indicators	Chicken groups			Norm (according to M. P. Babina)
	Control	ASP-34	GKPF-109	
Haemoglobin, h/l	100±3.3	95.0±1.89	104±2.3	92.71–101.5
Red blood cells, t/l	3.99±0.045	3.9±0.03***	4.06±0.034	2.2–2.3
White blood cells, g/l	22.7±0.02	24.6±0.02	28.4±0.7	29.2–32.6
Colour index	0.84±0.02	0.81±0.012	0.84±0.015	1–3
ESR, mm/h.	3.0±0.36	2.4±0.37 **	2.2±0.25***	1.0–3.0
Lymphocytes, %	60.6±1.08	62.71±0.64	60.8±1.44	58.7–60.84
Monocytes, %	4.0±0.37	3.71±0.42	4.1±0.35	6.28–8.52
Eosinophils, %	3.7±0.39	2.57±0.37***	2.8±0.33**	2.83–5.17
Basophils, %	0.7±0.26	1.0±0.31	1.0±0.26	0.24–0.96
Pseudoeosinophils, %	31.0±0.78	31.4±1.19	31.4±1.17	28.5–32.2
Platelets, thous./ml	37.5±0.91	38.0±0.93	38.4±0.79	50.7–62.6

***Note**: ** – P<0.01 probability in relation to the control, *** – P<0.001 probability in relation to the control*

***Table 4**. Immunological parameters of broiler chickens (m±m; n=10)*

Indicators, units of measurement		Chicken groups		
		control	ASP-34	GKPF-109
T-lymphocytes, %		35.7±0.94	36.2±0.41	35.5±0.36
T-helpers, %		24.1±0.66	24.2±0.38	23.1±0.59
T-suppressors, %		11.6±0.65	11.7±0.36	12.4±0.37
T active, %		2.2±0.32	2.9±0.18	2.14±0.26
T-resistant, %		5.5±0.31	5.8±0.29	4.71±0.56
T-0, %		49.7±0.90	49.2±0.53	51.54±0.69
IRI-insulin resistance		2.13±0.13	2.12±0.07	1.87±0.10
Phagocytic activity of neutrophils, %		60.0±1.30	62.5±1.12	60.0±1.90
Phagocytic number, units		3.6±0.22	3.2±0.20	2.86±0.26
Circulating immune complexes, units of optical density				
small molecular weight		17.1±3.63	30.9±5.07	15.3±1.72
medium molecular weight		11.5±3.42	21.8±2.60	11.43±1.17
large molecular weight		7.9±3.20	11.3±0.60	7.14±0.98
NST-test	+	14.2±0.42	14.2±0.47	11.28±0.60
	++	6.1±0.46	6.3±0.30	6.0±0.44
	+++	2.8±0.25	3.0±0.33	3.0±0.31

***Note**: there is no probability in relation to the control*

According to the results of the analysis of the haematological indicators of the blood of broilers, an increase in the number of haemoglobin and erythrocytes and the colour index was found, but there was a slight decrease in ESR. Analysing the data of immunological indicators of broilers revealed an increase in T-total lymphocytes.

No significant changes were registered in relation to T-helpers to T-suppressors compared to the control group. In the GKPF-109 group, the percentage of phagocytosing neutrophils increased by 2.5% compared to the control and to chickens from the ASP-34 group. The phagocytic number of the test compounds was also slightly lower than the control.

The biochemical parameters of the blood serum of the poultry were determined (Table 5). Thus, in broiler chickens in all experimental groups, the ALT level was higher than physiological norms. Cholesterol and total bilirubin levels in chickens in all experimental groups were within the normal range.

Table 5. *Biochemical parameters of broiler chickens (M±m; n=10)*

Indicators	Units of measurement	Chicken groups		
		control	ASP-34	GKPF-109
ALT	mmol/l	0.71±0.09	0.77±0.20	0.73±0.04
AST	mmol/l	2.63±0.13	2.63±0.13	2.66±0.12
Cholesterol	mmol/l	4.0±0.21	4.07±0.22	4.26±0.18
Total protein	g/l	32.0±2.00	33.3±3.53	32.0±1.15
Albumin	g/l	16.43±0,17	16.8±1.04	16.8±3.08
Urea	mmol/l	2.2±0.20	2.23±0.20	2.3±0.12
Bilirubin	mmol/l	1.0±0.03	0.96±0.03	0.83±0.23
Glucose	μmol/l	12.3±0.15	14.2±0.58	10.2±0.10

Note: *there is no probability in relation to the control*

The highest level of glucose was noted in the group with ASP-34, which was 14.2±0.58 mmol/l with a norm of 12.3 mmol, while in the group with GKPF-109 this indicator was lower than the control group and the norm. The amount of total protein, the level of which in broiler chickens ranges from 32 to 33 g/l, had some fluctuations in all experimental groups. The value of albumin in chickens was below the norm (44.5 g/l), the value was especially low in the group with ASP-34.

Analysing the above, it can be concluded that adding research compounds of the triazoline series to drinking water increases haematopoiesis, has anti-inflammatory and hepatoprotective effects. The next stage was organoleptic assessment of broiler chicken meat and broth (Figs. 3, 4).

Tasting evaluation of meat products and broth was carried out according to the generally expressed methodology described above (Table 6).

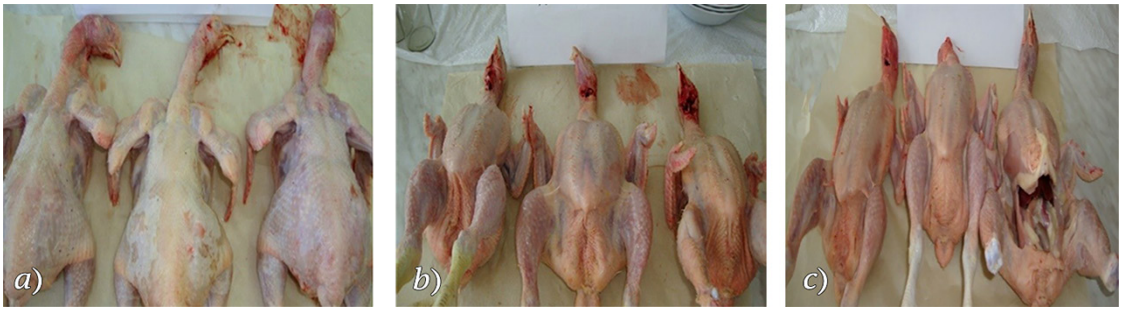

Figure 3. *Broiler chicken carcasses*

Note: *a) control; b) ASP-34; c) GKPF-109*

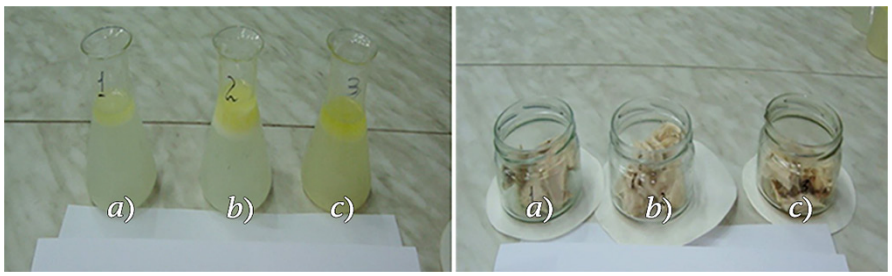

Figure 4. *Appearance of broiler chicken broth and boiled meat*

Note: *a) control; b) ASP-34; c) GKPF-109*

***Table 6**. Biochemical parameters of broiler chickens (M±m; n=10)*

Indicators	Group		
	control	ASP-34	GKPF-109
Arithmetic mean of the tasting assessment of meat products, score			
Colour	4.0	4.6	4.0
Smell	4.0	4.8	4.0
Fragrance	4.2	5.0	4.0
Tenderness	3.0	4.6	3.6
Taste	4.0	4.8	4.0
Juiciness	3.0	4.6	4.0
Total score	3.7	4.73	3.9
Arithmetic mean of the tasting assessment of broth quality, score			
Strength	3.6	4.8	3.8
Colour	4.0	4.8	4.4
Smell	4.0	5.0	4.0
Fragrance	3.8	4.8	4.0
Richness	3.4	4.8	3.6
Taste	4.0	4.8	3.4
Transparency	3.8	4.4	3.8
Total score	3.8	4.77	3.86

The assessment of the quality of cooked meat of broiler chickens in the ASP-34 group exceeded both the control group and the group that received GKPF-109. The total score in the ASP-34 group was 1.03 points higher than the control group, and 0.83 points higher than the GKPF-109 group. Furthermore, a higher evaluation of the broth was obtained in Group I, compared to the control by 0.97 points.

During the veterinary and sanitary evaluation of the poultry meat of the experimental and control groups, the surface of the carcasses in all samples was dry, white-yellow in colour with a pink tint; in the oral cavity, the mucous membrane was pink, moist; the beak was glossy; bulging eyeball; subcutaneous and internal adipose tissue was yellowish, the serous membrane of the chest and abdominal cavity was moist, the muscle tissue on the section was slightly moistened, pink, the smell was characteristic of fresh poultry meat. Broth in experimental samples was transparent, fragrant, in control samples – translucent, fragrant. No foreign smell was detected. No substantial differences were found in all indicators of the carcass of the experimental and control groups.

High-quality indicators of meat and broth in the experimental groups of broiler chickens indicate an improvement in the quality of meat when triazoline compounds were introduced into the diet.

Poultry farming is an essential and dynamically developing industry. In the structure of domestic poultry meat production, broiler chickens account for 97%, turkey accounts for 2%, and alternative poultry products (ducks, geese, quail) account for only 1% of the total volume. The population's need for animal proteins is met by chicken meat and eggs, the dietary properties of which are well-known. These are socially significant products that are available to the public due to their low cost.

The task of the poultry industry is to increase competitiveness by improving the quality and reducing the cost of the resulting products.

Currently, there is an active search for alternative drugs that would stimulate growth, contribute to the normalisation of the microbial composition of the digestive canal of chickens and ensure the production of high-quality and safe products. Intensive development of the poultry industry is impossible without the use of various biologically active additives. These supplements include probiotics, prebiotics, symbiotics, enzymes, organic acids, and triazoline-type compounds (Simmonds, 2017; Kabene & Baadel, 2019).

To understand the mechanism of action of individual drugs on the organs of the bird and the body as a whole, a complex morphological study of body tissues in different periods of development is necessary (Maguey-Gonzales, 2018; Mudroňová *et al.,* 2020; Arif *et al.,* 2018). Based on this, the purpose of the study was to comprehensively assess the effect of compounds of the triazoline series on haematological, immunological

indicators of blood and productive indicators of broiler chickens of the "Cobb-500" cross.

A tendency to increase the intensity of the growth rate of broiler chickens was found upon administering the compounds under study. During the same feed consumption, the growth rate of broilers in some experimental groups exceeded that of peers from the control group. The results of experiments on feeding triazoline compounds to broiler chickens indicate an increase in the stimulating effect, which implies a reduction in the time of industrial poultry rearing (Paliy & Paliy, 2022), which is relevant for industrial meat poultry farming (Disetlhe *et al.,* 2019; Jaďuttová *et al.,* 2019; Roth *et al.,* 2019).

The dynamics of the development of broiler chickens, which were in an experiment to study the effect of compounds of the triazoline series on meat productivity, showed that administering ASP-34 and GKPF-109 to broiler chickens led to a higher increase in live weight, compared to the control.

The highest average daily growth rate was observed during the rearing period from 24 to 30 days in the group with GKPF-109, which resulted in a chicken weight of 1,182.9±41.5 g, which exceeds the control by 116.7 g (10.9%) of the efficiency of using new derivatives of 1,2,4-triazole. An increase in average daily growth was found in the group that received GKPF-109 in the period from 15 to 55 days of rearing. This trend continued during the growing season from 22 to 26 days. Thus, the study established a positive effect of triazoline-series compounds and when administered at 0.1% concentration, which is economically advantageous. At the end of the 36th day of rearing, the excess live weight of chickens was found in comparison with the peers of the control group. Therewith, in 2 experimental groups that received ASP-34 and GKPF-109, live weight gain was obaserved. Administering 0.5% concentration of GKPF-109 showed an increase in stimulating activity on broiler chickens, which was 3.62% in the period from the 5th to the 10th day of cultivation.

The positive effect of triazoline compounds is also observed in the works of other scientists. Thus, M. Krauze et al. (2006; 2007) in their studies determined the effect of adding a synthetic 1,2,4-triazole derivative to drinking water for turkeys compared to garlic extracts and the echinovit drug. An increase in the number of leukocytes, the percentage of phagocytic cells and the phagocytic index was established. Lysozyme activity exceeded the indicator of the control and other groups of turkeys twice. Adding an aqueous extract of garlic or small doses of a synthetic derivative of 1,2,4 – triazole to drinking water during turkey rearing is effective in increasing non-specific cellular immunity. According to R.C. Simmonds (2017), by day 42 of rearing, Hubbard cross chickens had a weight of 1,835.0±35.0 g, while chickens of the experimental group had an average live weight of 2,065.0±25.0 g. In the given study on triazoline series compounds, the live weight of chickens and haematological indicators in all experimental groups exceeded the control, which is consistent with the results of the researchers mentioned above.

It is known that according to the age-related increase in the live weight of broilers, there is an increase in the weight of internal organs, including the thymus, the absolute weight of which increases unevenly throughout life (Simmonds, 2017; Kabene & Baadel, 2019).

The addition of triazoline compounds to the diet affected the activity of chicken blood enzymes. Analysis of the effect of the ASP-34 derivative on blood immunological parameters indicated an increase in the level of haemoglobin, red blood cells, and white blood cells compared to the control group. Other indicators were within the limits of physiological norms.

Immunological indicators also indicated a stimulating effect of triazoline-type compounds due to an increase in the number of T-lymphocytes, as well as a significant increase in T-helpers and B-lymphocytes. Analysing the average live weight of broilers at slaughter, which received GKPF-109, was 2,061 kg, which was higher than peers of the control group by 18.58%. In the same group, a higher percentage of meat yield was recorded, which was 84.31%.

Thus, the obtained results, based on a comprehensive assessment of the influence of compounds of the triazoline series during the period of growing broiler chickens, convincingly prove that they contribute to the improvement of haematological and immunological indicators of blood, increase in live weight, average daily gains, and obtaining high-quality and safe products.

CONCLUSIONS

Low weight gain of broiler chickens is one of the reasons restraining the growth of production of poultry products. Producers lose part of the profit in raising poultry. During the conducted research, it was established that administering new compounds of the triazoline series had a positive effect on the general condition of broiler chickens compared to the control group. In addition, broiler chickens of the experimental groups were more active and consumed food well. The use of 1,2,4-triazoline derivatives had a positive effect on the gastrointestinal rhythm of broiler chickens during the transition from one diet to another. During the experiment, a positive effect on the safety of broiler chickens treated with new triazoline compounds was established relative to the control group. Furthermore, compounds of the triazoline series showed a stimulating effect on increasing the live weight of the experimental groups. The technological methods of processing broiler chickens with new compounds of the triazoline series *in ovo* used in the experiment are economically feasible for increasing the efficiency of poultry farming. Thus, they ensure an increase in average daily live weight gains, the preservation of young animals, increase the meat productivity of broiler chickens, and provide non-specific resistance of the bird's body.

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Продуктивність та якість м'яса курчат-бройлерів при використанні нових сполук триазолінового ряду

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Анотація. У забезпеченні населення якісними продуктами харчування особливе місце приділяється м'ясному птахівництву. Метою роботи було вивчення впливу сполук триазолінового ряду на продуктивність та гематологічні показники курчат-бройлерів. Дослідження проводили в період з 2021 по 2022 р. у Одеському державному аграрному університеті в віварії та аналітичних лабораторіях. Для дослідження використовували похідні 1,2,4-тріазолу, синтезованих у Запорізькому державному медичному університеті: GKPF-109 – Morpholin-4-ium-2-((4-amino-5-(3-methyl-pyrazol-5-yl)-1,2,4-triazol-3-yl)thio)acetate; АСП-34 – sodium 2-((4-amino-5-(thiophen-2-ylmethyl)-4H-1,2,4-triazol-3-yl)thio)acetate. Динаміку приросту птиці визначали шляхом індивідуального зважування із подальшим визначенням абсолютних та середньодобових приростів живої маси. Годівлю птиці здійснювали згідно з видом і віковими періодами відповідно до існуючих норм. Гематологічні, імунологічні та біохімічні дослідження проводили згідно з методиками. Дегустаційну оцінку м'яса і бульйону проводили по 5-бальній системі, Бульйони оцінюються за 4 показниками – смаком, запахом, кольором, прозорістю кожен з них за 5 бальною системою. Аналіз даних загальної маси в групах вказує на найвищий валовий приріст живої маси в групі курчат 36-денного віку, яка отримувала GKPF-109 з 10-денного віку, що становить 14966 г за 26 днів досліду. Як можна побачити, що збереження курчат-бройлерів за період досліду в дослідних групах становить 96 %, а у контрольній — 94 %. Аналізуючи викладене вище можна зробити висновок, що додавання до питної води досліджувальні сполуки триазолінового ряду посилює гемопоез, має протизапальну та гепатопротекторну дію. Оцінка якості м'яса курчат-бройлерів та бульйону в кінці досліду не дозволяють стверджувати про зниження їх аромату та смакових якостей, що свідчить про відсутність негативного впливу досліджувальних сполук триазолінового ряду та способів їх застосування на органолептичні показники м'яса

Ключові слова: похідні 1,2,4-тріазолу, м'ясна продуктивність бройлерів, тушки птиці, приріст, маса

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Dynamics of Some Mineral Elements Content in the Muscle, Bone and Liver of Quails under the Apimin Influence

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Abstract. In the system of full-fledged poultry feeding, particular importance is attached to providing them with mineral substances. The purpose of this study was to determine the effect of the Apimin mineral additive based on bee podmore on the content of zinc, copper, magnesium, and iron in the meat, liver, and bone tissue of quails. During the study, the following methods were used: zootechnical (to analyse the productivity of quails), physiological (to determine the digestibility of nutrients in the poultry diet), biochemical (to analyse the content of minerals in muscles, liver, and tubular bones), morphological (to determine the meat qualities of quails: mass of edible parts, meat carcasses), statistical (to determine the presence or absence of a substantial difference between the values). Justification of the effectiveness of feeding the Apimin additive was carried out based on a comprehensive study on the chemical composition of Apimin, retention of minerals, meat indicators, dynamics of zinc, copper, iron, magnesium content in muscle, bone, and liver tissues of quail. The research was conducted on Pharaoh meat quail from 1 to 56 days of age and quails from 60 to 120 days. Apimin contains calcium, magnesium, iron, zinc, manganese, phosphorus, silicon, and selenium. Feeding Apimin increases metabolism, the digestibility of copper was higher by 21.7%, zinc – by 5.9%, iron – by 8.9%, and magnesium – by 12.9%. Including the additive in the diet influenced increasing muscle mass, the ratio of pulp to bone was higher by 0.26. The content of zinc in pectoral muscles increased by 15.6%, in femoral and lower leg muscles by 2.6%, in the liver – by 5.3%; in pectoral muscles iron increased by 5.1%, in liver– by 13.1%. The copper content was 8.0% higher in the thigh and lower leg muscles, 3.2% higher in the liver, and 14.0% higher in the pectoral muscles. No effect of Apimin on magnesium content was found. With age, the content of ash in the bones of quail fed with Apimin decreased by 3.87%, the content of copper increased by 18.3%, and zinc by 27.6%

Keywords: young quails, trace elements, mineral additive, meat qualities, mineral compositioncarcasses, growth, mass

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INTRODUCTION

Poultry farming is one of the most profitable production sectors in the world. Its main task is to increase the production of meat and eggs. Livestock breeders and consumers are interested in food products that contain plenty of wholesome bioactive components. In recent decades, a promising branch of poultry farming – quail farming – has been successfully developing. Quails have several advantages over other poultry species, one of which is that their growth rate is considerably higher than that of chickens (Khvostik & Bondarenko, 2021; Shelton & Southern, 2006). Therefore, to ensure this biological characteristic, they must be provided with nutritious food, and quite high requirements are imposed on poultry diets.

In Ukraine, poultry farmers breed quails of specialised egg and meat breeds. In terms of the efficiency of using feed in meat production, quails of meat breeds are not inferior to broilers. In the production of poultry products, safety and quality are important. Poultry meat is characterised by high nutritional, dietary, culinary, and technological value (Orkusz, 2015). Quail meat is a source of complete animal protein, low in fat and cholesterol (Moawad *et al.,* 2018). Quail meat is considered a valuable source of protein due to its good amino acid composition (Genchev *et al.,* 2008). Poultry meat contains an increased amount of polyunsaturated fatty acids, and it is more nutritious than chicken meat due to the content of various vitamins (B, A, E) (Khalifa *et al.,* 2016). Various minerals have also been found in quail meat, including calcium, phosphorus, sodium, potassium, magnesium, iron, copper, and zinc (Genchev *et al.,* 2008; Cullere *et al.,* 2018). In sufficient quantities, these minerals contribute to the formation of the skeletal system and animal health, given that various elements are involved in metabolism and maintaining the body's acid-base balance (Ravindran, 2014). Quail meat is also characterised by aroma and taste, it is tender and juicy (Genchev *et al.,* 2008).

Feeding is a vital component of livestock production technology, which provides animals and poultry with energy, nutrients, and biologically active components (Skoromna *et al.,* 2019). The availability of full-fledged feed, balanced in all nutritional indicators, largely determines the level of development of poultry farming. Among the main factors of nutrition, trace elements play a vital role, which take part in all physiological processes and are considered indispensable substances (Lemesheva & Yurchenko, 2016). Partial mineral deficiency causes particularly great losses to poultry farming, and the optimal content of trace elements in the diet ensures the normal state of poultry health, safety, and high productivity (Kyryliv *et al.,* 2017; Gutyj *et al.,* 2019). During the growth and development of birds, the content of mineral elements in their body increases, the mineralisation of skeletal bones increases, and the need for macro- and microelements increases (Shelton & Southern, 2006; Dozier *et al.,* 2003). Recently, animal husbandry has begun to use a variety of feed additives to enrich the diets of animals with mineral elements, which should enter their bodies in optimal quantities and proportions (Chudak *et al.,* 2019; 2020; Poberezhets *et al.,* 2021). They regulate the body's metabolism, provide optimal conditions for the activity of digestive enzymes in various parts of the gastrointestinal tract, and contribute to improving productivity and product quality (Yefimov & Masiuk, 2016; Nys *et al.,* 2018; Vargas-Sánchez *et al.,* 2019). Trace elements such as copper, iron, zinc, and manganese are essential for poultry growth and are involved in many digestive, physiological, and biosynthetic processes in the body (Milanović, 2008; Sunder, 2008). additiveation of the basic diet of broilers with trace elements affects the colour and moisture retention of the pectoral and thigh muscles (Yang *et al.,* 2011).

Given the above, there is a constant need to search for new feed additives. In many countries, numerous non-conventional feeds with low biological usefulness and nutritional value are used for feeding poultry. Non-conventional feed additives of natural origin are of considerable interest to scientists and practitioners. The use of feed additives from non-conventional plant raw materials in feed increases the slaughter weight of broiler chickens, provides an increase in the content of zinc, manganese, and iron in muscle and bone tissues (Gunchak *et al.,* 2016). Scientists and practitioners are interested in non-conventional feed additives of natural origin, which are by-products of industry, to replenish feed resources for animals and poultry (Plyska & Ibatullin, 2020; Bittencourt *et al.,* 2019). Among non-conventional feed additives, beekeeping waste is of particular interest, namely bee podmore, which is unique in its biochemical composition (Razanova, 2018). In beekeeping, its reserves are still completely unused. Bee podmore is a source of protein (up to 50%), fat, fibre, vitamins, and mineral elements. It also includes a chitosan-melanin complex, which, due to its radioprotective and sorption properties, can bind and remove toxic substances (Razanova *et al.,* 2018).

Scientists have investigated the beneficial properties of bee podmore on rabbits, gobies, pig breeding, and beekeeping (Razanova *et al.,* 2018; Gevlich *et al.,* 2013). The introduction of preparations and feed additives from the bee podmore contributed to an increase in metabolic processes, animal productivity, an increase in the number of red blood cells, haemoglobin content within the physiological norm, and an increase in the total protein level.

Recently, there has been an increase in poultry meat consumption all over the world. The growing level of demand for meat is affected by the quality of products. The use of various additives in poultry farming contributes not only to increased production of meat products, but also affects their quality, which requires monitoring the safety and quality of meat (Nawaz *et al.,* 2016;

Sałek *et al.,* 2020). Therefore, research on the impact of new additives in poultry feeding on the meat qualities and chemical composition of quail meat is relevant and of practical importance.

The purpose of this study was to investigate the effect of the Apimin mineral additive based on bee podmore on the content of zinc, copper, magnesium, and iron in quail meat and liver.

MATERIALS AND METHODS

When conducting research on quails, international and national biotic provisions on animal experiments were observed – the European Convention for the protection of vertebrates used for research and other scientific purposes of 1986, and the Law of Ukraine No. 3447-IV "On the Protection of Animals from Ill-Treatment".

200 meat quail (Coturnix coturnix Pharaoh) aged 1 day, including males and females, were used for the study. Poultry was divided into 2 groups of 100 heads using the method of balanced groups (Ibatullin *et al.,* 2017). When forming the groups, the age and live weight of the bird were considered. Quail were raised from one day to 56 days of age. For the further influence of the additive under study, at the age of 60 days, 2 groups of quail (25 heads each) were selected, which were raised until the age of 120 days. In the first series of quail studies, the duration of the experiment was 56 days (from 1 to 56 days), in the second – 60 days (from 60 to 120 days). Experimental studies were conducted by using a mineralized additive from bee podmore – Apimin – in feeding quails. Birds of the control group were fed the basic diet. Experimental quail of the second group were added to the diet with the addition of Apimin at a dose of 1.1 g/kg of mixed feed. The additive was thoroughly mixed with compound feed.

The maintenance and care of experimental quails during the experiment were the same. The parameters of the microclimate of the room corresponded to zoohygienic standards adopted for poultry. The quails were fed with a full-fledged compound feed, which was complete in terms of the content of macro- and microelements. The frequency of feeding was twice a day (morning and evening). After the end of the experimental periods, 4 birds from each group were slaughtered according to the methods of T. Polivanova (1988) and A. Genchev *et al.* (2008). Live weight of quail at slaughter, at 56 days of age, averaged 285.0 g in the control group and 297.5 g in the experimental group.

To obtain the Apimin mineralised additive, winter bee podmore was used, which was harvested in the spring in apiaries of the Vinnytsia Oblast. During the conducted research, an innovative method for solving the scientific problem of justification for the use of beekeeping waste to produce feed additives was proposed, which consisted in developing an appropriate technological solution for its production (mineralised additive) and an experimental study of its use in poultry feeding. To obtain the Apimin mineral additive, the bee podmore was first selected, then it was burned in a muffle furnace at 300°C. As a result, the Apimin additive was obtained. The yield of Apimin was 27 g per 100 g of bee podmore.

Apimine, according to the results of its mineral composition, contains macronutrients: calcium, magnesium, phosphorus, silicon, and trace elements – iron, magnesium, selenium, copper, and zinc (Table 1).

Table 1. *Mineral composition of Apimin*

Indicator	Content	Indicator	Content
Silicon, g/kg	27.705	Iron, g/kg	8.059
Calcium, g/kg	22.164	Magnesium, mg/kg	302.24
Magnesium, g/kg	25.186	Selenium, mg/kg	11.08
Phosphorus, g/kg	47.854	Copper, mg/kg	151.12
Sodium, g/kg	16.623	Zinc, mg/kg	50.37

Apimine contains a considerable amount of silicone, which plays an important role in the absorption of mineral elements such as calcium, phosphorus, magnesium, sulphur, potassium, and sodium.

The research materials were samples of meat, bones, liver, feed, and droppings. Samples of average muscle, bone, and liver tissue were taken during anatomical disassembly of quail carcasses.

In the samples under study, the content of magnesium, copper, zinc, and iron was determined by atomic absorption spectrophotometry (Lebedev & Usovych, 1976).

Biometric processing of the obtained research data was performed using MS Excel software with built-in statistical functions. Conventional symbols are used in the tables to show the level of probability: * – $p<0.05$; ** – $p<0.01$; *** – $p<0.001$.

RESULTS AND DISCUSSION

One of the priority tasks of poultry farming is to increase poultry productivity and expand the range of feed products with the use of mineral additives in feeding. In world practice, a considerable number of studies have been conducted on the use of additives in feeding various poultry species and areas of productivity (Bao *et al.,* 2007; Gutyj *et al.,* 2019; Nys *et al.,* 2018).

Y. Nys et al. (2018) analysed the role of essential

trace elements (zinc, copper, iron, manganese, iodine, and selenium) in feeding broilers and laying hens, determined the need for trace elements, bioavailability of trace element sources. The data obtained are consistent with the results of Y. Bao et al. (2007), who investigated the use of copper, zinc, iron, and manganese from organic sources in broiler diets. B. Kyryliv et al. (2017) obtained positive results in increasing the productivity of quail and improving the products obtained by introducing the "Belo-Akt" additive with minerals of copper, manganese, and zinc into the poultry diet. They established that when the supplement was introduced into the diet of quail, the live weight increased by 12.67%, the laying capacity by 7.37%, and the content of mineral elements in the eggs increased. Studies by P. Sałek et al. (2016) confirm the feasibility of introducing organic zinc additives with amino acids into the broiler diet, which improved the quality of the carcass and pectoral muscles. J. Shelton & L. Southern (2006) did not establish the effect of mineral additives on the growth rate of chickens, but the removal of trace element additives from the diet adversely affected the bone strength of poultry. G. Kim et al. (2011) investigated the effect of copper chelate supplementation on productivity, blood parameters, and mineral content in the liver of broiler chickens. They found that the concentration of copper in the liver increased with increasing levels of supplementation of this element. B. Gutyj et al. (2019) found that feeding laying hens with cadmium sulphate contributed to a decrease in the number of red blood cells, haemoglobin levels, and an increase in the number of white blood cells. The use of the Apimin feed additive in the diet of young quail contributed to an increase in their lifetime indicators of meat productivity. The bird of the experimental group grew more intensively and at the end of the experiment the live weight was 277.9 g against 267.2 g in the control group. That is, the advantage in the group of quail that were given the Apimin mineral additive in the diet was 4.0%.

The content of mineral elements in the bird's body depends on the intensity of metabolic processes (Kim *et al.,* 2011; Dozier *et al.,* 2003). Mineral mobilisation depends on the amount of food intake, the level of assimilation and distribution in the body (Bao *et al.,* 2007).

The highest level of assimilation of certain mineral elements was found in quail when feeding the Apimin mineral additive as part of the diet. In quail of this group, the absorption of copper was higher, compared with poultry of the control group, by 21.7%, zinc – by 5.9%, iron – by 8.9% and magnesium – by 12.9% at ($p<0.001$) (Table 2).

The mass of edible parts of quails increased most in the group of quails when they were fed the Apimin mineral additive as part of the diet (Table 3).

***Table 2**. Digestibility of feed trace elements by quails (M±m, n=4)*

Indicator	Group	
	Control	Experimental
Copper	41.9±0.38	67.4±0.54***
Zinc	77.3±0.34	89.9±0.13***
Iron	69.2±1.84	78.1±1.33***
Magnesium	59.5±2.11	72.4±1.27***

***Table 3**. Quail meat qualities (M±m, n=4)*

Indicator	Group	
	Control	Experimental
Output of edible parts, %	58.8±0.60	61.1±0.24*
Including femoral and tibial muscles	9.2±0.13	9.5±0.14
Pectoral muscles	15.1±0.07	16.8±0.23***
Liver	2.01±0.11	2.48±0.1*
Meat content of the carcass, %	61.4±0.28	63.5±0.38
Breast meatiness, %	24.0±0.06	26.6±0.26
Meatiness of the thighs and lower leg, %	14.6±0.19	15.2±0.06

Quail of the experimental group fed with the additive under study according to the results of the slaughter had a higher yield of edible parts of the carcass, namely, by 2.3% ($p<0.05$) compared to the analogues of the control group. Poultry of this group showed higher indicators in building muscle mass. Thus, the output of the femoral and tibial muscles was higher by 0.3%, and the pectoral muscles – by 1.7% ($p<0.001$).

Higher indicators were found in the experimental group of quail in terms of meat content of carcasses

by 2.1%, breasts – by 2.6%, thighs and shins – by 0.6%. The most valuable thing in carcasses is muscle tissue. Carcass in which the ratio of muscle tissue to bone is 4–4.5:1 is considered more valuable. According to the results of studies in the experimental group, a slightly higher indicator was obtained – 4.07:1 against 3.81:1 in the control group. That is, the difference between the indicator in the experimental groups was 0.26 in favour of the experimental group.

Minerals mainly accumulate in the muscles and liver (Zakharenko *et al.,* 2004). The liver is the main tissue depot where most minerals accumulate. Therefore, the liver plays an important role in the exchange of bioelements. Through it, mineral elements enter the blood and individual organs and tissues.

Analysis of the mineral content in the muscles and liver of quails showed certain changes in the introduction of Apimin into the diet (Table 4).

***Table 4**. Mineral composition of quail muscles and liver (M±m, n=4)*

Group	Trace elements			
	Copper, mg/kg	Zinc, mg/kg	Iron, mg/kg	Magnesium, g/kg
Pectoral muscles				
Control	5.56±0.017	10.95±0.144	24.33±0.687	0.57±0.014
Experimental	4.78±0.020***	12.65±0.104***	25.57±0.444	0.57±0.015
Femoral and tibial muscles				
Control	3.86±0.025	18.03±0.125	21.17±0.147	0.44±0.019
Experimental	4.17±0.020***	18.50±0.129*	21.16±0.155	0.43±0.020
Liver				
Control	8.96±0.091	103.0±0.18	543.1±10.11	54.0±0.08
Experimental	9.25±0.011	108.5±0.19	614.4±1.08	54.2±0.12

Zinc is an essential trace element for all living organisms. This element performs vital functions in the maintenance and development of the skeleton, is a structural component, a catalytic factor of enzymes, and part of vitamins and hormones (Bao *et al.,* 2007; Zakharenko *et al.,* 2004). The zinc content in the pectoral muscles significantly increased in the experimental group by 15.6% ($p<0.001$), in femoral and tibial muscles – by 2.6% ($p<0.05$), in the liver – by 5.3%.

Iron is an essential element for oxygen transport, the respiratory chain of mitochondria and cell proliferation, facilitates the survival of young animals and contributes to an increase in live weight (Bao *et al.,* 2007; Milanović *et al.,* 2008). Iron in the pectoral muscles of experimental quails was 5.1% more, and the content of this element in the femoral and lower leg muscles was not affected by feeding Apimin as part of the diet. The liver of quails of the experimental group contained 13.1% more iron ($p<0.001$). An increase in the content of this element in the liver of the experimental group of poultry indicates a high bioavailability of iron from the Apimin mineral additive.

Copper is involved in haemogenesis and promotes the formation of haemoglobin in the blood, is necessary for the normal development of the skeleton and increases meat productivity (Zakharenko *et al.,* 2004). In the femoral and tibial muscles of the poultry of the experimental group, the copper content was higher by 8.0% ($p<0.001$), in the liver – by 3.2%, and in the chest muscles, on the contrary, less – by 14.0% at ($p<0.001$) compared to the control group.

Magnesium is a calcium antagonist and is involved in many processes that occur in the muscles. Feeding quail as part of the diet of the Apimin mineral additive had almost no effect on the magnesium content in the muscles and liver.

Summarising the obtained research results, it is possible to state the positive effect of the Apimin additive based on bee podmore on the mineral composition of pectoral, femoral and lower leg muscles and liver.

According to the degree of metabolism in the skeleton of the bird's limbs, mineral metabolism can be traced both in the bones themselves and in the body as a whole. The bone tissue of tubular bones reacts to changes in the mineral composition of poultry diets (Pasnichenko, 2017).

In the group of quails that were fed the Apimin mineral additive as part of the diet, a higher yield of tubular bone ash was found (Table 5).

***Table 5**. Dynamics of zinc and copper content in quail tubular bones*

Indicator	Poultry age					
	60 days			120 days		
	ash, %	Copper, mg/kg	Zinc, mg/kg	ash, %	Copper, mg/kg	Zinc, mg/kg
Control	43.73±0.15	1.38±0.036	23.50±0.255	39.49±0.175	1.64±0.031	25.05±0.222
Experimental	46.55±0.14***	1.53±0.019**	23.78±0.293	42.68±0.20	1.81±0.02	30.35±0.171

Thus, in the bones of quail of the experimental group at the age of 60 days, ash was 2.82% more, at the age of 120 days – by 3.19%, compared to the control group. The ash content decreased with age in quail of the control group by 4.24%, in the experimental group – by 3.87%.

Copper and zinc also play a significant role in bone development. Zinc is involved in the renewal of bones and cartilage. Zinc and copper provide the strength of collagen. Copper is essential for the formation and functioning of elastin (Zakharenko *et al.,* 2004; Shelton & Southern, 2006).

Analysis of the content of copper and zinc in tubular bones shows that the introduction of Apimin into the poultry diet has a positive effect. Therewith, the copper content in the experimental group of quails of 60 days of age increased by 10.8%, 120 days of age – by 10.4% compared to the control group. With age, the amount of copper in the bones increased in the control group by 18.8%, the experimental group – by 18.3%.

There were also changes in the zinc content both with age and with the action of the mineral additive. Thus, zinc in the bones of quails of the experimental group aged 60 and 120 days was higher by 1.2% and 21.1%, respectively. In laying hens, the concentration of zinc increases during egg-laying: in the control group by 6.6%, in the experimental group – by 27.6%.

CONCLUSIONS

Studies have shown that the use of a mineral additive based on bee podmore (Apimin) increases the body's absorption of copper by 21.7%, zinc – by 5.9%, iron – by 8.9% and magnesium – by 12.9%.

Feeding young quail as part of the Apimin diet increased their live weight by 4.0%, meat content of carcasses – by 2.1%, breasts – by 2.6%, thighs and shins – by 0.6%, the ratio of pulp and bones – by 0.26.

The ash content of the pectoral muscles in the experimental group of quails increased with a higher content of some biogenic elements: zinc – by 15.6%, iron – by 5.1%, and copper – less by 14.0%, femoral and tibial muscles: zinc – by 2.6%, copper – by 8.0%, liver: zinc – by 5.3%, iron – by 13.1%, copper– by 3.2%. The additive had no effect on the magnesium content in the muscles and liver. With age, the amount of copper in quail bones increased in the control group – by 18.8%, the experimental group – by 18.3%, and zinc – by 6.6% and 27.6%, respectively.

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Динаміка вмісту деяких мінеральних елементів у м'язовій, кістковій тканинах та печінці перепелів за впливу апіміну

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Анотація. У системі повноцінної годівлі птиці важливе значення приділяється забезпеченості їх мінеральними речовинами. Мета дослідження полягала у визначенні впливу мінеральної добавки на основі бджолиного підмору апімін на вміст цинку, міді, магнію та заліза у м'ясі, печінці, кістковій тканині перепелів. Під час виконання дослідження були використані наступні методи: зоотехнічні (для аналізу продуктивності перепелів), фізіологічні (для визначення перетравності поживних речовин раціону птиці), біохімічні (для аналізу вмісту мінеральних речовин у м'язах, печінці та трубчастих кістках), морфологічні (для визначення м'ясних якостей перепелів: маса їстівних частин, м'ясності тушок), статистичні (визначали наявність або відсутність суттєвої різниці між значеннями). Обґрунтування ефективності згодовування добавки апімін здійснювалося на підставі комплексного дослідження з вивчення хімічного складу апіміну, ретенції мінеральних речовин, м'ясних показників, динаміки вмісту цинку, міді, заліза, магнію у м'язовій, кістковій тканинах та печінці перепелів. Дослідження проводили на перепелах м'ясної породи фараон з 1 до 56-денного віку і перепілках з 60 до 120 днів. У складі апіміну містяться кальцій, магній, залізо, цинк, марганець, фосфор, силіцій, селен. Згодовування апіміну сприяє підвищенню метаболізму, засвоюваність міді була вищою на 21,7 %, цинку – на 5,9 %, заліза – на 8,9 % і магнію – на 12,9 %. Додавання до раціону вплинуло підвищувало наростання м'язової маси, співвідношення м'якоті до кісток було вищим на 0,26 %. У грудних м'язах вміст цинку збільшився на 15,6 %, у стегнових і гомілкових м'язах – на 2,6 %, у печінці – на 5,3 %, заліза в грудних м'язах збільшився на 5,1 %, печінці – на 13,1 %. У м'язах стегна та гомілки вміст міді на 8,0 % вищий, у печінці – на 3,2 %, у грудних м'язах – на 14,0 %. Не виявлено впливу апіміну на вміст магнію. Вміст золи з віком в кістках перепілок за годівлі апіміном зменшився на 3,87 %, підвищився вміст міді – на 18,3 %, цинку – на 27,6 %

Ключові слова: молодняк перепелів, мікроелементи, мінеральна добавка, м'ясні якості, мінеральний склад

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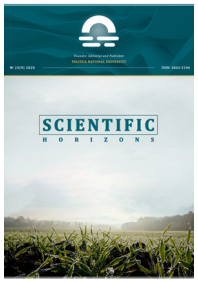

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Toxicity and Virucidal Activity of Chlorine Dioxide Disinfectant

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Abstract. The implementation of intensive technologies to produce livestock products requires the use of disinfectants at all stages. Analysis of the effectiveness of disinfectants begins with testing at the stage of creating or selecting substances, since different disinfectants have different activity against microorganisms, are toxic, immunosuppressive, and cause long-term effects on animals. This necessitates further development and research of preparations with optimal toxicity and virucidal action. The purpose of this study was to investigate the toxicity and virucidal effect of the new Diolide disinfectant, specifically on such samples as Aujeszky's disease virus, swine enzootic encephalomyelitis virus (Teschen disease) and rabies virus. The study was conducted according to national and international guidelines for the characterisation of virucidal properties of new disinfectants. The toxicity of Diolide disinfectant was investigated under protein load conditions in SPEV and BHK-21/C13 cell cultures. The virucidal activity of the Diolide disinfectant was determined under protein load conditions on models of shell viruses of Aujeszky's disease (Arsky strain) and rabies virus (CVS-11 strain) and using shell-free virus of enzootic encephalomyelitis of swine (Perechinsky-642 strain). The toxicity of Diolide disinfectant was determined for 0.16% (400 mg/l), 0.1% (250 mg/l), 0.06% (150 mg/l), 0.02% (50 mg/l), 0.008% (20 mg/l) and 0.004% (10 mg/l) concentrations of chlorine dioxide with an exposure time of 30 and 60 minutes. The virucidal effect of the preparation was determined for 0.1% (250 mg/l), 0.06% (150 mg/l), 0.02% (50 mg/l), 0.008% (20 mg/L) and 0.004% (10 mg/l) concentrations relative to the working dilutions of viral suspensions: for the Aujeszky's disease virus – 5.3 CPE_{50}/ml – for swine enzootic encephalomyelitis virus – 5.5 CPE_{50}/ml, for rabies virus – 5.5 $TCID_{50}$/ml. The results of the study showed that Diolide disinfectant is non-toxic to transplanted SPEV and BHK-21/C13 cell cultures in 0.1% (250 mg/l), 0.06% (150 mg/l), 0.02% (50 mg/l), 0.008% (20 mg/l) and 0.004% (10 mg/l) concentrations of chlorine dioxide. The preparation is 100% virucidal against enveloped viruses such as Aujeszky's disease virus (Arsky strain) and rabies virus (CVS-11 strain) in concentrations from 0.1% (250 mg/l) to 0.004% (10 mg/l) when exposed for 30-60 minutes under protein load conditions. It has 100% virucidal activity against the shell-free enzootic encephalomyelitis virus of swine (Perechinsky-642 strain) in concentrations from 0.1% (250 mg/l) to 0.004% (10 mg/l) at an exposure of 60 minutes and in concentrations from 0.1% (250 mg/l) to 0.008% (20 mg/l) at an exposure of 30 minutes under protein load conditions. The coefficient of reduction of infectious activity of the enzootic encephalomyelitis virus of swine (Perechinsky-642 strain) established in experiments after 30 minutes of exposure with the Diolide disinfectant at a concentration of 0.004% (10 mg/l) under protein load conditions exceeded 4 lg (4.47 lg CPE_{50}/0.02 ml), which indicates a high virucidal activity of the Diolide disinfectant. Further research may be aimed at further increasing the virucidal activity of the disinfectant

Keywords: disinfection, Aujeszky's disease virus, swine enzootic encephalomyelitis virus, rabies virus, virus titre, cell culture

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INTRODUCTION

Disinfection of pathogens is a necessary part of any modern commercial production, which is crucial both in obtaining high-quality products and in a complex of veterinary and sanitary measures for the prevention of the introduction of pathogenic microorganisms and the development of opportunistic microorganisms, the elimination of infectious diseases at veterinary supervision facilities (Paliy *et al.,* 2018; Wales *et al.,* 2021).

One of the components of the effectiveness and efficiency of any medical and preventive measures is the comprehensive use of disinfectants. The main purpose of disinfection is to create conditions for breaking the epizootic chain. To solve this problem, biocidal products are used, which are designed to destroy, neutralise, or inhibit the reproduction of bacteria, viruses, and fungi by chemical or biological means. The main factors affecting the effectiveness and efficiency of disinfectants are the spectrum of antimicrobial action (effectiveness against viruses and bacteria at different ambient temperatures and pH, no mutagenic effect on microorganisms), safety (no embryotoxic, teratogenic, carcinogenic, allergenic, and cumulative properties), corrosion activity, high permeability, environmental safety, etc. (Wales *et al.,* 2021; Chechet, 2022).

Currently, there are no ideal disinfectants, which encourages researchers to search for new compounds and study various combinations of known chemical compounds as disinfectants (Matsuzaki *et al.,* 2021; Cadnum *et al.,* 2021; Edmiston *et al.,* 2020).

It can be considered that one of the universal means of disinfection is sodium hypochloride and glutaraldehyde. However, they are corrosive, and their vapours adversely affect humans and animals (Rutala & Weber, 2019). That is why in developing disinfectants, the top priority is to create a best broad-spectrum disinfectant, which is non-toxic, non-irritating, non-corrosive, safe for humans, animals, and the environment (Rabenau *et al.,* 2020; Wales *et al.,* 2021).

In the last decade, chlorine dioxide (ClO_2) has been increasingly used as an effective biocide, both in soluble and gaseous forms. Chlorine dioxide is effective against bacteria, viruses, protozoa, mould and yeast fungi, mycobacteria, and bacterial spores. This chemical compound has powerful oxidising properties, thanks to which it destroys the protein structures of the cell wall or viral envelope. The chlorine dioxide molecule is oxidised with high efficiency, and therefore considerably affects viruses even at low concentrations (Miura & Shibata, 2010). Given that chlorine dioxide is a strong oxidising agent, disinfectants based on it are widely used for sterilisation, disinfection, and wastewater treatment. Chlorine dioxide is used for disinfection of drinking water and the environment, for disinfection of vegetables and fruits (strawberries, lettuce, cabbage, cucumbers) in gaseous form (Yu *et al.,* 2014). Furthermore, chlorine dioxide-based disinfectants can be used in medical institutions and public places where bioaerosols are significant (Du *et al.,* 2017).

Notably, chlorine dioxide does not belong to chlorine-type disinfectants, it does not enter chlorination reactions, does not produce carcinogens and is a safe compound for human body cells. At the same time, its biocidal effect on pathogens such as bacteria, viruses, fungi, and other pathogens is more powerful than that of chlorine due to active oxygen (Hsu *et al.,* 2015).

The most dangerous group of pathogenic microorganisms are viruses because the vast majority of nosological units of particularly dangerous infectious diseases of animals and humans are caused by viruses. The introduction of such pathogens into livestock or poultry farms causes mass deaths and the need for strict anti-epizootic measures, where forced disinfection is a part (Mummert & Weiss, 2017; Kindermann *et al.,* 2020; Wales & Davies, 2021).

It is known that animal viruses are classified into six groups and, depending on the structure, type of viral genome and size, differ in their resistance to disinfectants (Paquette *et al.,* 2020; Tarka & Nitsch-Osuch, 2021).

For a broad scientific assessment of new disinfectants for their virucidal activity, it is necessary to use various viruses, including shell-free ones, which are resistant to acidic pH values (International Committee..., 2022). Given that viruses must multiply in cell cultures, the virucidal activity should also be determined in culture systems, which will vary depending on the test virus used (Rabenau *et al.,* 2020).

Recommendations for the practical use of disinfectants that can be obtained from the results of tests in cell cultures are quite limited, since the conditions modelled in homogeneous suspensions are not factually found in practice. However, conclusions about the overall activity of the disinfectant under study, including under simulated protein load conditions, can be drawn from the results of tests in cell culture.

The purpose of this study was to investigate the toxicity and virucidal activity of the Diolide disinfectant preparation in cell culture on models of Aujeszky's disease virus, porcine enzootic encephalomyelitis virus (Teschen disease) and rabies virus.

MATERIALS AND METHODS

The toxicity and virucidal activity of Diolide disinfectant were studied according to national and international guidelines (Rabenau *et al.,* 2020; Kovalenko & Nedosekov, 2011).

The object of the study was the Diolide disinfectant, which is a two-component powdered product. Active substances of component 1: sodium chlorite – 42%, sodium chloride – 46%, functional additives – 12%. Active substances of component 2 are citric acid – 95%, adipic acid – 3%, functional additives – 2%.

To obtain the necessary working concentrations of the Diolide disinfectant, water of standard hardness was used, which was obtained according to the method (Rabenau *et al.,* 2020).

The toxicity study of the Diolide disinfectant was performed in re-grafted cell cultures of SPEV and BHK-21/C13 (ATCC CCL-10).

The virucidal effect of the Diolide disinfectant was determined under protein load conditions (adding 10% FBS to the DMEM medium) on models of Aujeszky's disease virus (Arsky strain); swine enzootic encephalomyelitis virus (Perechinsky-642 strain) and rabies virus (CVS-11 strain, ATCC VR 959). The infectious titre of virus-containing suspensions used in the studies was 7.31±0.20 lg CPE 50/ ml for the Aujeszky's disease virus (Arsky strain); swine enzootic encephalomyelitis virus (Perechinsky-642 strain) – 9.52±0.25 lg CPE_{50}/ ml; rabies virus (CVS-11 strain) with infectious activity – 7.53±0.11 lg TCID50/ml.

The following reagents were used for the research: DMEM (Dulbecco's Modified Eagle Medium), Sigma (GB); Fetal Bovine Serum (FBS), Gibco (Brazil); Dulbecco's Phosphate Buffered Saline (DPBS), Sigma (GB); Trypsin-EDTA (0.5%), no phenol red, Gibco (GB); Plasmocin, InvivoGen (France); Antibiotic-Antimycotic, Sigma (Israel); culture microplates (96 well), Sarstedt (Germany); Tissue Culture Flask (75 cm^2), Sarstedt (Germany); AR grade acetone, 80%, (Ukraine); FITC Anti-Rabies Globulin Kit, Fujirebio (USA).

Research was conducted using the following equipment: Esco CelCulture and Jouan 150 CO_2 incubators; microscope C.Zeizz – Aviovert 40CFL; fluorescent inverted microscope Zeiss AXIOVERT 25CA; Eppendorf and Biohit variable volume dispensers for 20-200 and 100-1,000 µl; biological safety cabinets Jokan MSC9; Holten SAFE-2010 and Hereus HS-18; Neubauer chamber for cell counting.

Study of the toxicity of the Diolide disinfectant. SPEV and BHK-21/C13 cell cultures were prepared in 96-well microplates (seeding concentration 1–1.2x105 cells per well). After 24 hours, the medium was removed from the 96-well microplates (provided that 80-90% of the monolayer is present) and corresponding dilutions of the disinfectant were made at 0.05 ml/well. Experimental dilutions of the Diolide disinfectant in the final concentration according to chlorine dioxide 0.16% (400 mg/l), 0.1% (250 mg/l), 0.06% (150 mg/l), 0.02% (50 mg/l), 0.008% (20 mg/l) and 0.004% (10 mg/l) were previously prepared from 20% disinfectant and 80% DMEM medium (with 10% FBS).

Contact of SPEV and BHK-21/C13 cells with corresponding disinfectant dilutions was carried out in an incubator at 37°C (for BHK-21/C13 cell culture, also 5% CO_2) for 30 and 60 minutes. For one concentration of Diolide disinfectant, 32 wells were used.

To control SPEV and BHK-21/C13 cells, a mixture of 80% DMEM medium (with 10% FBS) and 20% sterile water of standard hardness was used, which was introduced into 32 wells of a 96-well microplate of 0.05 ml/well for the same period of contact of cells with the disinfectant.

At the end of the contact period, disinfectant solutions were removed from 96-well microplates, DPBS was washed three times, and 0.20 ml of a supporting medium containing 10% FBS was introduced into the wells. Incubation of 96-well micro-panels with SPEV and BHK-21/C13 cell cultures was performed for 72 hours using daily monolayer microscopy of cells in wells to detect the cytopathic effect (CPE). The presence of a cytopathic effect was evaluated visually, and the presence of a monolayer of cells was expressed as a percentage.

Study of the virucidal effect of the Diolide disinfectant. The specific effect of the Diolide disinfectant was determined for concentrations of 0.16% (400 mg/l), 0.1% (250 mg/l), 0.06% (150 mg/l), 0.02% (50 mg/l), 0.008% (20 mg/l) and 0.004% (10 mg/l). Test objects: Aujeszky's disease virus (Arsky strain), swine enzootic encephalomyelitis virus (Perechinsky strain-642) and rabies virus (CVS-11 strain, ATCC VR 959). SPEV and BHK-21/C13 cell cultures were pre-inoculated in 96-well microplates (inoculation concentration for both cell lines was 1-1.2x105 cells per well). The selection of viruses was based on several factors, namely: 1) viruses that do not cause (rabies virus) and cause CPE (Aujeszky's disease virus and swine enzootic encephalomyelitis virus); 2) shell-containing viruses (rabies virus and Aujeszky's disease virus) and shell-free viruses (swine enzootic encephalomyelitis virus).

The necessary amount of virus was added to the determined experimental dilutions of the Diolide disinfectant to obtain its working dilution. In each experiment, the working dilution of viral suspensions was obtained based on virus activity titres: for Aujeszky's disease virus – 5.3 lg CPE_{50}/0.2 ml, for swine enzootic encephalomyelitis virus – 5.5 lg CPE_{50}/0.2 ml, and for rabies virus – 5.5 lg TCID50/0.2 ml.

Contact (exposure) of viral suspensions with corresponding dilutions of the disinfectant was carried out at room temperature (recommended for disinfection) for 30 and 60 minutes. 32 wells with SPEV and BHK-21/C13 cell cultures were used for each concentration of Diolide disinfectant. Later, corresponding dilutions of the disinfectant with viruses were made as follows:

- disinfectant dilution + working dilution of Aujeszky's disease virus (Arsky strain) on a daily monolayer of SPEV cell cultures;
- disinfectant dilution + working dilution of swine enzootic encephalomyelitis virus (Perechinsky-642 strain) on a daily monolayer of SPEV cell cultures;
- dilution of disinfectant + working dilution of rabies virus (CVS-11 strain) on a daily monolayer of BHK-21/C13 cell culture.

In all experiments, the mixture of the working dilution of the virus and experimental dilutions of the Diolide disinfectant in cell cultures was adsorbed within 60 minutes.

Then, to neutralise the action of the disinfectant, the dilution of the disinfectant with viruses was removed from 96-well micro-panels, DPBS was washed three times and 0.20 ml of the supporting medium with a content of 10% FBS was introduced into the wells.

96-well micropanels with SPEV cell culture, in which various concentrations of the Diolide disinfectant and working dilutions of the Aujeszky's disease virus (Arsky strain) and swine enzootic encephalomyelitis virus (Perechinskyi-642 strain) were added, were incubated for 72 hours with daily microscopy of the monolayer of cells in the wells for the detection of cytopathic effect. In each experiment, to control the titre of infectious activity of the applied viruses, titration of the working dose of viral suspensions was performed.

96-well micropanels with BHK-21/C13 cell culture, in which different concentrations of disinfectant and working dilution of rabies virus (CVS-11 strain, ATCC VR 959) were added, were incubated for 72 hours. After the end of the incubation period, the cells in the wells were fixed with 80% acetone and after drying they were stained with FITC Anti-Rabies Globulin Kit. After washing the DPBS cells, the presence of a specific glow of the rabies virus was evaluated under a luminescent microscope.

To control the cells, a mixture of 80% DMEM medium (with 10% FBS) and 20% sterile water of standard hardness was used, which was introduced into 32 wells of a 96-well microplate for the same period of adsorption of the virus mixture with Diolide disinfectant. Virus suspensions in working dilution were used as positive controls (virus of Aujeszky's disease – 5.3 lg CPE_{50}/0.2 ml, virus of enzootic encephalomyelitis of swine – 5.5 lg CPE_{50}/0.2 ml, rabies virus – 5.5 lg TCID50/0.2 ml).

The specific effect of Diolide disinfectant on experimental viruses was expressed in the absence of virus expression in cell cultures, namely: the absence of CPE in SPEV cell culture for Aujeszky's disease viruses and enzootic encephalomyelitis of swine, as well as in the absence of a specific glow of rabies virus in BHK-21/C13 cell culture with visual detection of characteristic changes in positive controls.

RESULTS AND DISCUSSION

The study of the Diolide disinfectant was performed in two stages. The first stage involved the detection of cytotoxic effects in transplanted SPEV and BHK-21/C13 cell culture lines, and the second – directly virucidal activity against three different viral strains.

Study of the toxicity of the Diolide disinfectant. The manifestation of the cytotoxic effect was determined for 0.16% (400 mg/l), 0.1% (250 mg/l), 0.06% (150 mg/l), 0.02% (50 mg/l), 0.008% (20 mg/l) and 0.004% (10 mg/l) concentrations of Diolide disinfectant in SPEV and BHK-21/C13 cell cultures at 30 and 60 minutes of exposure (Table 1).

Table 1. *Cytotoxic effect of various concentrations of Diolide disinfectant in SPEV and BHK-21/C13 cell cultures, n=3*

Final concentration of Diolide disinfectant for chlorine dioxide	Exposition	Presence of a monolayer of cells in 96-well micro-panels, %					
		SPEV cell culture			cell culture BHK-21/C13		
		24 hours	48 hours	72 hours	24 hours	48 hours	72 hours
0.16% (400 mg/l)	30 min	10	10	20	0	0	0
0.1% (250 mg/l)		80	80	90	80	80	80
0.06% (150 mg/l)		80	100	100	80	80	90
0.02% (50 mg/l)		90	100	100	90	90	90
0.008% (20 mg/l)		90	100	100	80	100	100
0.004% (10 mg/l)		90	100	100	90	100	100
control		90	100	100	80	100	100
0.16% (400 mg/l)	60 min	0	0	0	0	0	0
0.1% (250 mg/l)		80	90	90	70	80	80
0.06% (150 mg/l)		80	100	100	80	80	100
0.02% (50 mg/l)		90	100	100	80	90	100
0.008% (20 mg/l)		90	100	100	80	90	100
0.004% (10 mg/l)		90	100	100	90	100	100
control		90	100	100	80	100	100

The digital material presented in Table 1 shows that the use of Diolide disinfectant in different concentrations caused different manifestations of cytotoxic effects on SPEV and BHK-21/C13 cells.

A substantial cytotoxic effect (90-100% cell death in the central part of the wells for 24 hours of cultivation, changes in the morphostructure and lack of active proliferation of living cell residues) of the Diolide disinfectant was established in SPEV and BHK-21/C13 cell cultures at a concentration of 0.16% (400 mg/l) at an exposure of 30 and 60 minutes. In a separate experiment, after exposure as an inactivator of the action of the active components of the Diolide disinfectant, a 50% FBS solution was added to SPEV cells for 30 minutes, but it was not possible to get rid of the cytotoxic effect (20-40% of cells remained alive and no proliferation was observed for 72 hours cultivation).

The use of Diolide disinfectant at a concentration of 0.1% (250 mg/l) did not cause cell death or other cytotoxic manifestations that can be identified visually. However, during the entire follow-up period (72 hours), cell proliferation was insignificant compared to the control cells SPEV and BHK-21/C13 at 30 and 60 minutes of exposure.

In SPEV and BHK-21/C13 cells treated with Diolide disinfectant at concentrations of 0.06% (150 mg/l), 0.02% (50 mg/l), 0.008% (20 mg/l) and 0.004% (10 mg/l) at exposure for both 30 and 60 minutes, no cell death was detected during the entire follow-up period (72 hours). Cell proliferation and visual filling of the monolayer were comparable to similar cells in the control group.

Study of the virucidal effect of Diolide disinfectant. Considering the results obtained to investigate the cytotoxic manifestation of various working dilutions of Diolide disinfectant in SPEV and BHK-21/C13 cell cultures, concentrations of 0.1% (250 mg/l), 0.06% (150 mg/l), 0.02% (50 mg/l), 0.008% (20 mg/l), and 0.004% (10 mg/l) were selected to study its direct virucidal effect.

To investigate the virucidal activity of the Diolide disinfectant, DNA- and RNA-containing viruses were used, namely Aujeszky's disease virus (DNA-containing, family Herpesviridae, Arsky strain); swine enzootic encephalomyelitis virus (RNA-containing, family Teschovirus, Perechinsky-642 strain); rabies virus (RNA-containing, family *Rhabdoviridae*, CVS-11 strain).

The study of the virucidal effect of the Diolide disinfectant on the model of the DNA-containing virus of Aujeszky's disease (Arsky strain) in the SPEV transplantable culture system showed that 0.1% (250 mg/l), 0.06% (150 mg/l), 0.02% (50 mg/l), 0.008% (20 mg/l), and 0.004% (10 mg/l) concentrations of the Diolide disinfectant both during 30 minutes of exposure and during 60 minutes of exposure, provided absolute (100%) virucidal effect (Table 2).

***Table 2**. Virucidal effect of Diolide disinfectant on Aujeszky's disease virus (Arsky strain) in SPEV cell culture, n=3*

Final concentration of Diolide disinfectant for chlorine dioxide	Exposure, min	Presence of a virus	Cell control	Virus control (CPE presence)
0.1% (250 mg/l)	30	—	#	+
	60	—	#	+
0.06% (150 mg/l)	30	—	#	+
	60	—	#	+
0.02% (50 mg/l)	30	—	#	+
	60	—	#	+
0.008% (20 mg/l)	30	—	#	+
	60	—	#	+
0.004% (10 mg/l)	30	—	#	+
	60	—	#	+

***Note**: "—" is the absence of CPE in cell culture; "+" is the presence of CPE in cell culture; "#" is the presence of 100% monolayer at 72 hours of cultivation in all control wells of a 96-well plate*

In all wells with SPEV cells, in which mixtures of different concentrations of Diolide disinfectant and working dilution (5.3 lg CPE_{50}/0.2 ml) of the Aujeszky's disease virus (Arsky strain), no CPE was detected, which would indicate virus reproduction (Figure 1a – concentration of 0.06% (150 mg/l) at 60 minutes of exposure; Figure 1b – concentration of 0.004% (10 mg/l) at 60 minutes of exposure).

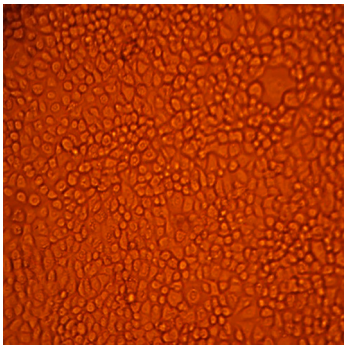

***Figure 1a**. SPEV cell culture Aujeszky's disease virus (Arsky strain) + Diolide at a concentration of 0.06% (150 mg/l) at an exposure of 60 minutes, 24 hours of cultivation*

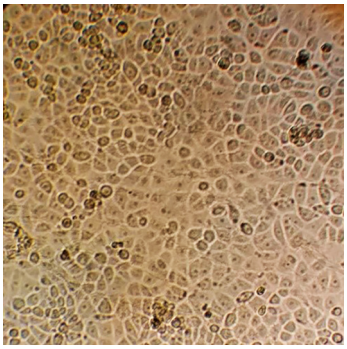

***Figure 1b**. SPEV cell culture Aujeszky's disease virus (Arsky strain) + Diolide at a concentration of 0.004% (10 mg/l) at an exposure of 60 minutes, 72 hours of cultivation*

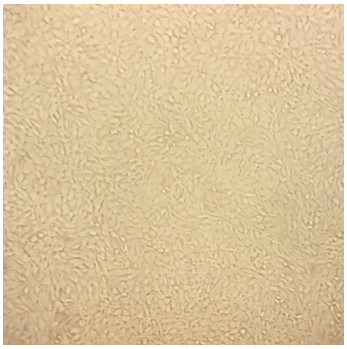

***Figure 1c**. SPEV cell culture Cell control, 48 hours of cultivation*

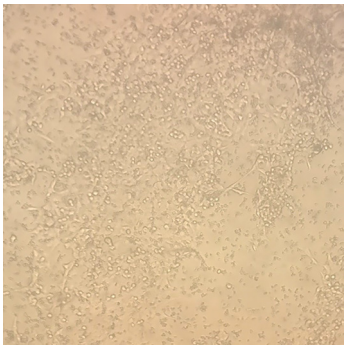

***Figure 1d**. SPEV cell culture Control of Aujeszky's disease virus (Arsky strain), CPE in cell culture for 24 hours of cultivation*

SPEV cells in the control wells remained intact for the entire follow-up period, forming a 100% monolayer after 72 hours of incubation (Figure 1c). In wells with virus control (Figure 1d), 100% CPE was noted as early as 24 h after infection. The infectious titre of the working dose of the Aujeszky's disease virus (Arsky strain) used in the experiments was 5.22±0.15 lg CPE_{50}/0.02 ml.

Experiments on the characterisation of the virucidal effect of the Diolide disinfectant on a model of the RNA-containing virus of enzootic encephalomyelitis of swine (Perechinsky-642 strain) in the re-grafted culture system SPEV showed slightly different results (Table 3).

***Table 3**. Virucidal effect of Diolide disinfectant on swine enzootic encephalomyelitis virus (Perechinsky-642 strain) in SPEV cell culture, n=4*

Final concentration of Diolide disinfectant for chlorine dioxide	Exposure, min	Presence of a virus	Cell control	Virus control (CPE presence)
0.1% (250 mg/l)	30	—	#	+
	60	—	#	+
0.06% (150 mg/l)	30	—	#	+
	60	—	#	+
0.02% (50 mg/l)	30	—	#	+
	60	—	#	+
0.008% (20 mg/l)	30	—	#	+
	60	—	#	+
0.004% (10 mg/l)	30	+	#	+
	60	—	#	+

***Note**: "—" is the absence of CPE in cell culture; "+" is the presence of CPE in cell culture; "#" is the presence of 100% monolayer at 72 hours of cultivation in all control wells of a 96-well plate*

It was found that 0.1% (250 mg/l), 0.06% (150 mg/l), 0.02% (50 mg/l), 0.008% (20 mg/l), and 0.004% (10 mg/l) concentrations of Diolide disinfectant during 60 minutes of exposure provided a 100% virucidal effect relative to the working dose of enzootic encephalomyelitis virus used in SPEV cells (Figure 2a – concentration of 0.1% (250 mg/l) at an exposure of 60 minutes; Figure 2b – concentration of 0.004% (10 mg/l) at an exposure of 60 minutes).

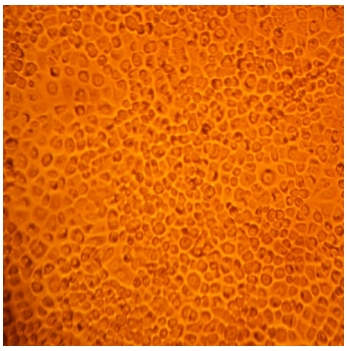

***Figure 2a**. SPEV cell culture Swine enzootic encephalomyelitis virus (Perechinsky-642 strain) + Diolide preparation in a concentration of 0.1% (250 mg/l) at an exposure of 60 minutes, 48 hours of cultivation*

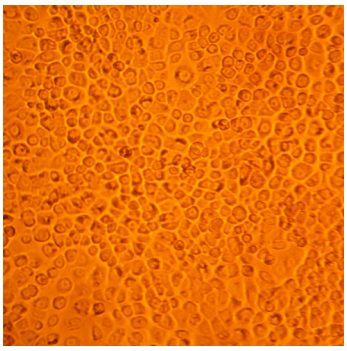

***Figure 2b**. SPEV cell culture Swine enzootic encephalomyelitis virus (Perechinsky-642 strain) + Diolide preparation in a concentration of 0.004% (10 mg/l) at an exposure of 60 minutes, 24 hours of cultivation*

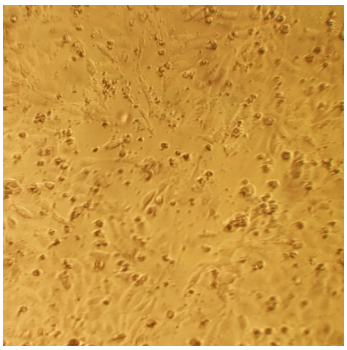

***Figure 2c**. SPEV cell culture Swine enzootic encephalomyelitis virus (Perechinsky-642 strain) + Diolide preparation in a concentration of 0.004% (10 mg/l) at an exposure of 30 minutes, 48 hours of cultivation*

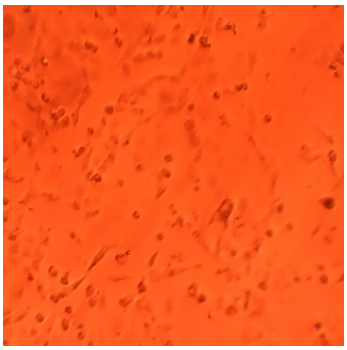

***Figure 2d**. SPEV cell culture Control of swine enzootic encephalomyelitis virus (Perechinsky-642 strain), CPE in cell culture for 24 hours of cultivation*

However, after 30 minutes of exposure and a concentration of 0.004% (10 mg/l), residual infectious activity of the swine enzootic encephalomyelitis virus was detected (Figure 2c), which was manifested as CPE after 48 hours of cell culture. Determination of the infectious activity of swine enzootic encephalomyelitis virus (Perechinsky-642) after 30 minutes of exposure with Diolide disinfectant at a concentration of 0.004% (10 mg/l) showed a titre of 1.25±0.19 lg CPE_{50}/0.02 ml.

The virus control (Fig. 2d) showed 100% CPE as early as 24 hours after infection, and the SPEV cells in the control wells remained intact for the entire follow-up period.

Determination of the infectious titre of the working dose of swine enzootic encephalomyelitis virus (Perechinsky-642), which was used in experiments, showed a titre of 5.72±0.12 lg CPE_{50}/0.02 ml. That is, the decrease in infectious activity (reduction coefficient – RF) of the pig enzootic encephalomyelitis virus (Perechinsky-642 strain) after 30 minutes of exposure with Diolide disinfectant at a concentration of 0.004% (10 mg/l) was 4.47 lg CPE_{50}/0.02 ml.

The disinfectant is considered to have caused a sufficient reduction in the titre if the average RF is at least 4 lg. That is, a decrease in the infectious activity of the enzootic encephalomyelitis virus of pigs when using the Diolide disinfectant at a concentration of 0.004% (10 mg/l) for more than 4 lg is an acceptable virucidal effect (especially for shell-free viruses and in studies under protein load conditions).

In another series of experiments, the virucidal activity of the Diolide disinfectant was investigated on a model of a shell RNA-containing rabies virus (CVS-11 strain) in a transplanted BHK-21/C13 culture system. Studies have shown that 0.1% (250 mg/l), 0.06% (150 mg/l), 0.02% (50 mg/l), 0.008% (20 mg/l), and 0.004% (10 mg/l) concentrations of Diolide provided 100% virucidal action during 30 and 60 minutes of exposure (Table 4).

***Table 4**. Virucidal effect of Diolide disinfectant on rabies virus (CVS-11 strain) in BHK-21/C13 cell culture, n=3*

Final concentration of Diolide disinfectant for chlorine dioxide	Exposure, min	Presence of a virus	Cell control	Virus control (presence of TCID)
0.1% (250 mg/l)	30	—	#	+
	60	—	#	+
0.06% (150 mg/l)	30	—	#	+
	60	—	#	+
0.02% (50 mg/l)	30	—	#	+
	60	—	#	+
0.008% (20 mg/l)	30	—	#	+
	60	—	#	+
0.004% (10 mg/l)	30	—	#	+
	60	—	#	+

***Note**: "—" is the absence of specific fluorescence in cell culture; "+" is the presence of a specific glow in the cell culture; "#" is the presence of 100% monolayer at 72 hours of cultivation in all control wells of a 96-well plate*

In all wells with BHK-21/C13 cells, in which mixtures of different concentrations of Diolide disinfectant and working dilution (5.5 lg $TCID_{50}$/0.2 ml) of rabies virus (CVS-11 strain), no specific glow was detected at 72 hours of incubation, which indicated no reproduction of the virus. In wells with virus control after 72 hours, a specific glow of the rabies virus was detected (Figure 3a – transplanted culture of VNA-21/C13 cells for 48 hours of incubation after applying the rabies virus and Diolide at a concentration of 0.1% (250 mg/l) at an exposure of 60 minutes; Figure 1b – control of the virus in the VNA-21/C13 culture for 72 hours of incubation). Titration revealed that the infectious activity of the working dose of rabies virus (CVS-11 strain) was 5.82±0.07 lg $TCID_{50}$/0.2 ml.

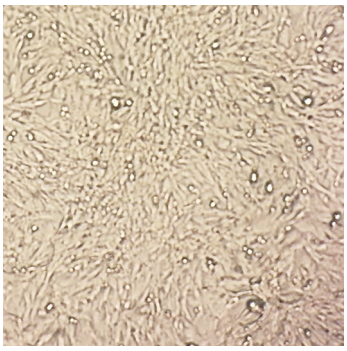

***Figure 3a**. Culture of BHK-21/C13 cells. Rabies virus (CVS-11 strain) + Diolide preparation at a concentration of 0.1% (250 mg/l) at an exposure of 60 minutes, 48 hours of cultivation*

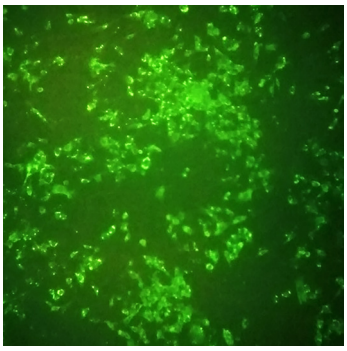

***Figure 3b**. Luminescence microscopy of rabies virus (CVS-11 strain) in BHK-21/C13 cell culture after 72 hours of incubation*

According to J. Ma et al. (2017), the antiviral activity of chlorine dioxide is detected after 2 minutes for H1N1 virus and influenza Type B virus. T. Sanekata et al. (2010) evaluated the antiviral activity of chlorine dioxide solution against feline calicivirus, influenza virus, measles virus, canine distemper virus, human herpes virus, human adenovirus, canine adenovirus, and canine parvovirus. Chlorine dioxide in low concentrations was found to exhibit strong antiviral activity, inactivating 99.9% of viruses at 15-second exposure (Yu *et al.,* 2010; Ogata & Shibata, 2008).

In this study, the high virucidal activity of various concentrations of the Diolide disinfectant, the main active substance of which is chlorine dioxide, was similarly established. The studies used other animal viruses as models, namely Aujeszky's disease virus, swine enzootic encephalomyelitis virus (Teschen disease) and rabies virus. A prerequisite for the use of these viruses was the toxicity study of the Diolide disinfectant, which was tested on two re-grafted cultural systems: SPEV and BHK-21/C13.

Thus, the results of laboratory tests presented in this paper indicate the safety and high efficiency of 0.1-0.004% concentration of the Diolide disinfectant based on chlorine dioxide, which opens up prospects for its wide application in production in the implementation of preventive and forced disinfection treatment of surfaces and liquids.

CONCLUSIONS

1. Diolide disinfectant is non-toxic to re-grafted SPEV and BHK-21/C13 cell cultures in 0.1% (250 mg/l), 0.06% (150 mg/l), 0.02% (50 mg/l), 0.008% (20 mg/l),

and 0.004% (10 mg/l) concentrations of chlorine dioxide.

2. Diolide disinfectant has 100% virucidal activity against envelope viruses, such as Aujeszky's disease virus (Arsky strain) and rabies virus (CVS-11 strain) in concentrations from 0.1% (250 mg/l) to 0.004% (10 mg/l) when exposed for 30-60 minutes under protein load conditions.

3. Diolide disinfectant has 100% virucidal activity against the shell-free virus of enzootic encephalomyelitis of swine (Perechinsky-642) in concentrations from 0.1% (250 mg/l) to 0.004% (10 mg/l) at an exposure of 60 minutes and in concentrations from 0.1% (250 mg/l) to 0.008% (20 mg/l) at an exposure of 30 minutes under conditions of protein load.

4. The coefficient of reduction of infectious activity of the enzootic encephalomyelitis virus of swine (Perechinsky-642 strain) after 30 minutes of exposure with Diolide disinfectant at a concentration of 0.004% (10 mg/l) under protein load conditions exceeded 4 lg (4.47 lg CPE_{50}/0.02 ml).

5. The results of laboratory tests indicate a high virucidal activity of the Diolide disinfectant and give grounds for its widespread introduction into production.

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Токсичність та віруліцидна активність дезінфекційного засобу на основі діоксиду хлору

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Анотація. Впровадження інтенсивних технологій виробництва продукції тваринництва вимагає використання дезінфікуючих засобів на всіх етапах. Аналіз ефективності дезінфектантів починається з випробування на етапі створення або відбору речовин, оскільки різні дезінфікуючі засоби мають різну активність проти мікроорганізмів, є токсичними, імуносупресивними та спричиняють довготривалий вплив на тварин. Це зумовлює необхідність подальшої розробки та досліджень засобів із оптимальними показниками токсичності та віруліцидної дії. Метою статті є дослідити токсичність та віруліцидну дію нового дезінфікуючого засобу «Діолайд», зокрема на таких зразках як вірус хвороби Ауєскі, вірус ензоотичного енцефаломіеліту свиней (хвороби Тешена) та вірус сказу. Дослідження проводили відповідно до національних і міжнародних керівництв щодо характеристики віруліцидних властивостей нових дезінфікуючих засобів. Вивчення токсичності дезінфікуючого засобу «Діолайд» проводили за умов білкового навантаження в культурах клітин SPEV та BHK-21/C13. Визначення віруліцидної активності дезінфікуючого засобу «Діолайд» проводили за умов білкового навантаження на моделях оболонкових вірусів хвороби Ауєскі (штам «Арський») і вірусу сказу (штам CVS-11) та використовуючи безоболонковий вірус ензоотичного енцефаломіеліту свиней (штам «Перечинський-642»). Токсичність дезінфікуючого засобу «Діолайд» визначали для 0,16 % (400 мг/л), 0,1 % (250 мг/л), 0,06 % (150 мг/л), 0,02 % (50 мг/л), 0,008 % (20 мг/л) та 0,004 % (10 мг/л) концентрацій за двоокисом хлору з тривалістю експозиції 30 та 60 хвилин. Віруліцидну дію засобу визначали для 0,1 % (250 мг/л), 0,06% (150 мг/л), 0,02% (50 мг/л), 0,008% (20 мг/л) та 0,004 % (10 мг/л) концентрацій відносно робочих розведень вірусних суспензій: для вірусу хвороби Ауєскі – 5,3 CPE_{50}/ml, для вірусу ензоотичного енцефаломієліту свиней – 5,5 CPE_{50}/ml, для вірусу сказу – 5,5 $TCID_{50}$/ml. Результати дослідження показали, що дезінфікуючий засіб «Діолайд» не токсичний для перещеплюваних культур клітин SPEV та BHK-21/C13 в 0,1 % (250 мг/л), 0,06 % (150 мг/л), 0,02 % (50 мг/л), 0,008 % (20 мг/л) та 0,004 % (10 мг/л) концентраціях за діоксидом хлору. Препарат 100% віруліцидно діє щодо оболонкових вірусів, таких як вірус хвороби Ауєскі (штам «Арський») та вірус сказу (штам CVS-11) в концентраціях від 0,1 % (250 мг/л) до 0,004 % (10 мг/л) за експозиції 30–60 хвилин в умовах білкового навантаження. Має 100 % віруліцидну активність щодо безоболонкового вірусу ензоотичного енцефаломіеліту свиней (штам «Перечинський-642») в концентраціях від 0,1 % (250 мг/л) до 0,004 % (10 мг/л) за експозиції 60 хвилин та в концентраціях від 0,1 % (250 мг/л) до 0,008 % (20 мг/л) за експозиції 30 хвилин в умовах білкового навантаження. Встановлений в дослідах коефіцієнт зниження інфекційної активності вірусу ензоотичного енцефаломіеліту свиней (штам «Перечинський-642») після 30 хвилин експозиції з дезінфікуючим засобом «Діолайд» в концентрації 0,004 % (10 мг/л) в умовах білкового навантаження становив більше 4 lg (4,47 lg CPE_{50}/0,02 ml), що свідчить про високу віруліцидну активність дезінфекційного засобу «Діолайд». Подальші дослідження можуть бути спрямовані на подальше підвищення віруліцидної активності дезінфікуючого засобу

Ключові слова: дезінфекція, вірус хвороби Ауєскі, вірус ензоотичного енцефаломіеліту свиней, вірус сказу, титр вірусу, культура клітин

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Blood Parameters of Rabbits Given Different Amounts of Iodine Citrate

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Abstract. The need for iodine in rabbit diets has not been fully elucidated, although some commercial diets use it in varying amounts without scientific justification. The main goal of the experiment was to establish the effect of applied quantities of an organic iodine compound produced by nanotechnology – iodine citrate – on blood parameters of rabbits after weaning from 40 to 96 days of age. Experimental studies were conducted in the conditions of the vivarium of the scientific institution – Institute of Animal Biology of the National Academy of Sciences of Lviv on 30 rabbits of the Termonska breed. The control and experimental groups had the same number of 6 animals, of which 3 were males and 3 were females. Young rabbits of the control group were kept on standard granulated compound feed and water without restriction. In contrast to the control, the animals of I, II, III, and IV experimental groups additionally received a solution of iodine citrate in the amount of 2.5; 3.75; 5.0 and 7.5 μg/l of water, respectively. Blood parameters were determined on the 40th day of life (preparatory period) and on the 18th, 43rd and 56th days of iodine citrate supplementation. Studies have established a higher number of red blood cells and haemoglobin concentration in the blood of rabbits of Group II ($P \leq 0.05$) on the 43rd and 56th days; Group III ($P \leq 0.05$) and Group IV ($P \leq 0.05$-0.01) on the 18th, 43rd, and 56th days of the study. The haematocrit value of the blood of rabbits of Group II was respectively higher by 16.6% on the 56th day; Group III – by 17.1%; 20.0%, and 22.8%, and in Group IV – by 26.4%; 29.4%, and 23.5% on the 18th, 43rd, and 56th days of the study. The albumin content in the blood of rabbits of Group I was higher by 4.1% on the 43rd day; Group II – by 6.8%; 8.0%; 9.5%; Group III – by 6.1%; 4.6%; 9.5%; Group IV – by 4.5%; 2.7%; 7.3% on the 18th, 43^{rd,} and 56th days of the study, respectively. The content of total calcium in the blood of rabbits of Group II exceeded the control by 22.5% on day 43, the level of inorganic phosphorus in the blood of rabbits of Groups II, III, and IV was respectively higher by 5.8%, 5.0%, and 4.1% on the 56th day of the study compared to the control

Keywords: nanocompound, metabolism, erythrocytes, calcium, phosphorus

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INTRODUCTION

The use of nanoparticle compounds in industrial intensive animal husbandry has attracted great research interest due to their unique properties in the body. The special sizes of nanoparticles from 1 to 100 Nm change their characteristics of the effect in the compound, which is manifested by activating properties on the course of biochemical reactions of the body (Khan *et al.,* 2019). The main function of iodine in the mammalian body is the metabolism of thyroid biologically active substances, which regulate energy metabolism. The synthesis of thyroid hormones requires a constant supply of the trace element iodine from the feed of the diet, which is provided from the soil. Therefore, for the full functioning of the mammalian body, it is necessary to constantly provide it with iodine (Babic Leko *et al.,* 2019). Separate studies established a substantial effect of organic iodine compounds on the body's metabolism. Thus, the drinking of various amounts of citrate I, Se, and S solution to broiler chickens produced by nanotechnology was described by changes in the haematological, biochemical, and productive parameters of their body. Chickens of Group II received the lowest dose of I, Se, S at the rate of 5 μg I/l, 1.25 μg Se/l, 7.5 μg S/l of liquid, in experimental poultry their number increased by 2 (III), 4 (IV), 6 (V), and 8 (VI) times compared to Group II. On the 35th day of the experiment, an increase in the content of cholesterol, triacylglycerols and albumin in the blood of Groups II, III, and VI of chickens was found, and a decrease in creatinine – in Groups III and VI. Compared to Groups I, II, III, under these conditions, the content of urea, Ca, P, cholesterol, and albumin in the blood of chickens of Groups IV, V, and VI significantly increased only in Group IV on the 48th day. The results obtained indicate a different effect of nano-supplementation depending on the amount used (Fedoruk *et al.,* 2021). A study was conducted to investigate the properties of iodine-containing nanoparticles that can absorb X-rays and determine the boundaries of the tumour in a fluorescent way. Radiation therapy of the brains of mice with orthotopic human gliomas and triple-negative human breast cancer showed considerable prolongation of their lives when iodine-containing nanoparticles were included (Hainfeld *et al.,* 2022). Studies established the importance of iodine for the animal body, its involvement in the synthesis of thyroid hormones, and the causes of iodine-deficient diseases. The antioxidant, antimicrobial, and antitumour effects of iodine were proved (Tronko & Kravchenko, 2021). The use of copper iodide nanoparticles in the diet of male rats increased thyroid hormones compared to a control group that did not receive these supplements (Ulwali *et al.,* 2019). Upon examining pregnant women in the endemic zone, thyroid dysfunction was noted, of which 62.4% were found to be deficient in iodine in the body at the end of pregnancy. In 37.6% of pregnant women, the concentration of iodine excretion in the urine exceeded 100 μg/l, which may lead to the idea of optimal iodine intake into the body, but insufficient for physiological processes in pregnant women (Kravchenko & Medvedev, 2018). The world is systematically improving programmes for correcting mineral nutrition, namely the added use of various sources of iodine in the human diet (Delshad *et al.*, 2018). Studies were conducted to determine the content of thyroid hormones in the body of rabbits. There was a positive and statistically significant correlation between serum and urine triiodothyronine (r=0.76) and a high positive correlation between serum and faecal triiodothyronine concentrations (r=0.62). It was found that the correlation of concentrations of other thyroid hormones between serum, urine, and faeces was insignificant. The physiological functioning of thyroid hormones is essential for rabbit metabolism, energy homeostasis, and reproduction (Chmurska-Gasowska *et al.,* 2021). The study of the effect of antioxidants and sources of organic iodine, *Laminaria digitate* – Group II and *Cystoseira barbata* – Group III, on blood parameters of California rabbits was marked by a significant increase in the level of thyroxine, total protein, and albumin in the experimental groups. In the meat of rabbits of the Group II, a significant excess of iodine content was found by 81.0 μg, and in animals of the Group III – by 234.1%. Animals of the experimental groups were characterised by higher productivity on day 90 of the study (Zuboshenko *et al.,* 2020). Added drinking of iodine in the form of the "*Jodis Concentrate*" preparation in the diet of repair female rabbits increased the development of follicles in the ovaries and contributed to more intensive protein expression in rabbit oocytes, which positively affected the reproductive function of female rabbits (Abadjieva *et al.,* 2018).

Drinking different amounts of mineral nanoparticles in the composition I, Se, S affected the dose-dependent effect on the body of rabbits after weaning. A large amount of the compound used was marked by higher indicators of haematopoiesis, protein levels, amino transferase activity, and activation of resistance of the rabbit body up to 110 days of age (Boiko *et al.,* 2021). It is necessary to note the activating effect of drinking nanocompounds of trace elements Silicon and Zinc on the body of rabbits after weaning, which was marked by higher blood parameters, within physiological values and productivity at the end of the experiment (Lesyk *et al.,* 2020; Boiko *et al.,* 2020).

In the diets of rabbits, iodine standards for different age groups were not established. However, iodine deficiency in the diet of fattening rabbits adversely affected their health, productivity, and the preservation of livestock. Commercial diets use iodine supplements in the form of sea salt or potassium iodide or iodate, which range from 0.2 to 2 mg/kg (De Blas & Wiseman, 2020).

Since there are several questions regarding the need and dosage of iodine in the diet of rabbits, including its organic compounds, it is necessary to conduct additional research.

The purpose of the experiment was to investigate the effect of different amounts of iodine citrate on changes in haematological and biochemical parameters of rabbit blood after weaning in the period from 40 to 96 days of life.

MATERIALS AND METHODS

The experimental part of this study was carried out based on the equipped vivarium of the Institute of Animal Biology of the National Academy of Sciences, Lviv. 30 rabbits-analogues of the Termon breed were selected for the study. Animals after weaning (40 days of life) were divided into five groups, with the control group consuming balanced pelleted feed and water without restriction. Rabbits of experimental Groups I, II, III, and IV, apart from balanced granulated compound feed, additionally received iodine citrate with water at a dose of 2.5, 3.75, 5.0 and 7.5 μg I/l of water, respectively. The used additive was obtained from Nanomaterials and Nanotechnologies LLC, Kyiv (Ukrainian patent for utility model No. 38391. IPC, 2006). The experimental period continued for 66 days, of which 10 days were the equalisation period and 56 days were the period for determining the main planned parameters of the blood of rabbits, the material for research was selected on the 58th, 83rd, and 96th days of life (18th, 43rd, and 56th day of drinking supplements) in 6 animals (3 males and 3 females) from the group. The total number of red blood cells, white blood cells, haemoglobin concentration and haematocrit value were determined in the blood using a Mythic-18 haematological analyser. Blood samples for haematological studies were collected in special test tubes with pre-introduced anticoagulant dicalcium salt of ethylenediamine — tetra acetic acid (EDTA – K2+), after which no later than four hours determination was made using the device and the indicators under study were obtained. Determination of the content of albumin, creatinine, urea, Ca, and P in plasma was performed on a biochemical analyser "Humalazer-2000" (Germany) using reagents of the company "LACHEMA" (Czech Republic) (Vislo, 2012). All manipulations with animals were performed per bioethical standards that meet the requirements of the European Convention for the protection of vertebrates used for experimental and scientific purposes (1986) and the resolution of the First National Congress on Bioethics (2001). Statistical processing of the obtained digital material was calculated using the Student's t-test. The average digital data was considered statistically significant when the differences in indicators between the control and research groups were less than $P<0.05$.

RESULTS AND DISCUSSION

In the conditions of industrial intensive rabbit breeding, each part of the diet is essential. Providing the body of rabbits with nutrients during the physiological stress of weaning rabbits is a critical period that affects the productivity of animals during rearing. It is also important to provide the body with minerals, namely iodine compounds. However, there is not much literature data to justify its quantities, while in commercial diets for rabbits it is used in different amounts. Conducted research on the use of organic iodine in compounds with other elements resulted in positive changes in their body (Boiko *et al.,* 2021; Fedoruk *et al.,* 2021). Literature data indicate the need for periodic studies of the blood of rabbits with industrial maintenance, as an effective and rapid marker of providing their body with nutrients from the diet (Chmurska-Gąsowska *et al.,* 2021). Drinking different amounts of iodine citrate in the diet of rabbits from the 40th day of life was marked by changes in the ratio of shaped blood elements. Thus, in the blood of rabbits of the second experimental group, the number of red blood cells was higher by 26.5% and 28.5%, respectively, on the 43rd and 56th days of the study compared to the control (Table 1).

***Table 1**. Absolute content of red blood cells, white blood cells, concentration of haemoglobin and haematocrit in the blood of rabbits after drinking various amounts of iodine citrate (M±m, n=6)*

Indicator	Animal group	Study periods			
		Preparatory	Research (day of life/day of study)		
		40th day	58/18	83/43	96/56
Red blood cells, 10^{12}/l	C	4.8±0.11	4.9±0.12	5.5±0.20	5.4±0.27
	E-I	4.6±0.22	5.11±0.19	5.8±0.18	5.4±0.25
	E-II	4.9±0.20	5.0±0.23	**6.2±0.11***	**6.3±0.18***
	E-III	4.7±0.21	**5.5±0.17***	**6.3±0.10****	**6.4±0.20***
	E-IV	4.8±0.23	**5.7±0.25***	**6.1±0.12***	**6.3±0.12***

Table 1, Continued

Indicator	Animal group	Study periods			
		Preparatory 40th day	Research (day of life/day of study)		
			58/18	83/43	96/56
Haemoglobin, h/l	C	111.9±0.79	122.2±4.08	126.8±4.12	130.2±3.58
	E-I	113.0±0.96	124.0±5.05	132.3±4.75	141.3±3.56
	E-II	110.3±2.81	129.8±4.92	**144.6±4.49***	**144.1±3.08***
	E-III	110.7±1.93	**140.0±4.02***	**148.5±5.12***	**147.3±5.55***
	E-IV	109.2±3.49	**142.3±4.93***	**152.5±5.11****	**148.8±4.41****
White blood cells, 10^9/l	C	6.4±0.24	6.0±0.28	7.0±0.35	7.2±0.43
	E-I	5.9±0.20	6.3±0.27	7.6±0.26	7.8±0.41
	E-II	6.0±0.20	6.6±0.34	6.8±0.36	7.6±0.45
	E-III	5.9±0.26	6.4±0.32	7.3±0.26	7.9±0.11
	E-IV	5.7±0.30	6.9±0.33	6.8±0.47	7.7±0.35
Haematocrit, l/l	C	0.33±0.011	0.35±0.013	0,37±0.015	0.37±0.017
	E-I	0.35±0.012	0.38±0.021	0.38±0.020	0.40±0.015
	E-II	0.36±0.014	0.37±0.022	0.40±0.014	**0.42±0.010***
	E-III	0.35±0.015	**0.41±0.015***	**0.42±0.014***	**0.43±0.019***
	E-IV	0.34±0.010	**0.43±0.016****	**0.44±0.008***	**0.42±0.013***

***Note**: in this and the following tables, statistically likely differences were taken into account in comparison with the control group: * – P≤0.05; ** – P≤0.01; *** – P≤0.001, where K is the control group, D – i; D-II; D-III; and D-IV-a solution of iodine citrate was drunk at the rate of 2.5; 3.75; 5.0 and 7.5 micrograms and/L of water, respectively*

Larger applied quantities of the trace element in the diet were characterised by a pronounced effect in the blood of animals of Group III with an increase in the number of erythrocytes by 17.0%; 34.0% and 36.6% and Group IV – by 18.7%, 27.0% and 31.2% on the 18th, 43rd, and 56th days of the study, respectively, compared to the control group of animals. The results of the red blood cell count correlated with the concentration of haemoglobin in the blood of rabbits. The dependence of these blood parameters in rabbits was also noted by other researchers (Sukar et al., 2020). In this study, such relationships were noted depending on the amount of supplement used. The level of haemoglobin in the blood of rabbits of Group II exceeded the control level by 31.0% and 30.6% on the 43rd and 56th days of the experiment, respectively. The level of this indicator in the blood of rabbits of Group III was higher by 26.4%, 34.1% and 33.0%, and Group IV – by 30.3%, 39.6% and 36.2% on the 18th, 43rd, and 56th days of the experiment, respectively, compared to the control. Notably, the smallest amount of iodine citrate applied (2.5 μg I/l of water) to animals and the experimental group did not affect the statistically significant changes in the indicator of red blood cells and haemoglobin, but only a tendency to their highest level.

Leukocytes are blood cells that perform a protective function, their number in the body of rabbits is within wide physiological parameters. Therefore, monitoring their level is important for assessing the state of immunobiological function of the rabbit body. Drinking iodine citrate in various amounts did not affect the significant changes in the number of white blood cells, which were within physiological values and indicated a stable physiological state of the body and the absence of a negative effect of the applied additive of nanotechnological origin.

The value of the haematocrit in the blood indicates the ratio of its liquid part and the number of shaped elements. In general, this indicator of changes in the number of blood cells corresponded to relative fluctuations in the body's liquid transport system, which is characterised by a higher functional ability depending on the trace element used. Thus, the haematocrit value of the blood of rabbits of Group II was higher by 16.6% in the final stage of the study. While in the blood of rabbits of Group III, its value was higher compared to the control by 17.1%, 20.0% and 22.8%, respectively, and in Group IV by 26.4%, 29.4% and 23.5% on the 58th, 83rd and 96th days of animal life. The obtained results of the study of the functional number of shaped elements and their ratio to the liquid part of the blood of rabbits may indicate an intensive metabolism in the body with different amounts of organic iodine in the diet, which activates the biosynthesis of thyroid hormones and triggers a cascade of biochemical reactions, which positively affected the metabolism and haematopoiesis in the body.

Added drinking of iodine citrate in the diet of rabbits was affected by a number of changes in the albumin content, which depended on the amount and duration of use of the supplement (Table 2).

***Table 2**. Some biochemical parameters of rabbit blood for drinking different amounts of iodine citrate (M±m, n=6)*

Indicator	Group	Research periods			
		preparatory, 40th day of life	experimental (age/day of drinking supplements)		
			58/18	83/43	96/56
Albumins, g/l	C	41.07±0.45	41.96±0.53	41.08±0.33	42.30±1.01
	E-I	41.61±0.61	41.88±0.39	**43.35±0.46****	44.22±0.88
	E-II	41.39±0.59	**44.22±0.43****	**44.72±1.03****	**45.35±0.47***
	E-III	41.40±0.68	**43.96±0.30****	**43.33±0.74***	**45.37±0.75***
	E-IV	42.39±0.64	**44.30±0.59****	**43.54±0.63****	**45.50±0.65***
Creatinine, μmol/l	C	91.3±3.98	119.6±12.08	128.0±6.50	120.0±5.94
	E-I	90.3±2.08	113.4±5.02	114.8±1.66	117.4±3.40
	E-II	96.8±3.15	119.4±10.53	122.3±8.18	121.8±5.15
	E-III	91.7±2.46	113.8±6.38	115.3±12.24	126.2±3.97
	E-IV	93.6±2.39	110.2±6.90	113.5±9.27	118.9±9.37
Urea, mmol/l	C	4.90±0.51	5.03±1.01	6.90±1.53	7.75±0.64
	E-I	5.20±0.77	4.28±0.86	5.98±1.19	7.43±0.66
	E-II	5.10±0.66	6.13±1.48	6.95±0.66	7.58±0.54
	E-III	4.40±0.62	4.48±0.89	6.10±0.98	6.63±0.33
	E-IV	4.30±0.64	4.35±0.61	6.95±0.37	6.80±0.58

In particular, the level of albumin in the blood of rabbits and the experimental group was 4.1% higher on the 43rd day of the study relative to the control. Considerably more significant differences were noted for the use of larger amounts of iodine citrate. Thus, the albumin content in the blood of rabbits of the II experimental group was respectively higher by 6.8%, 8.0%; 9.5%; Group III by 6.1%; 4.6%; 9.5%; Group IV – by 4.5%, 2.7%; 7.3% on the 18th, 43rd and 56th days of the study compared to the control group. Statistically significant differences between the experimental and control groups of animals constitute a positive factor in the activation of metabolic processes and non-specific protection of the body under the influence of iodine citrate in a larger amount used. It is known from the literature that albumin is synthesized in the liver, in hepatocytes, by the activity of the preproalbumin gene (Wouw & Joles, 2022). In rabbits, the liver is the main organ of metabolic processes. Perhaps the combination of the activating effect of organic iodine on thyroid hormones stimulated energy metabolism through a series of biochemical reactions in the body of rabbits. In addition, it is known that plasma proteins are involved in the protective processes of Innate and adaptive immune mechanisms, through the complement system using the CR1 receptor and due to their phagocytic properties (erythrophagocytosis), red blood cells can eliminate pathogens. In addition, they are likely involved in the immune response as antigen-presenting cells via Class II major histocompatibility complex antigens (Anderson *et al.,* 2018). Provide non-specific resistance activity of humoral and cellular type organisms (Yassin *et al.,* 2021). It is necessary to note the correlation between the level of albumin and the number of erythrocytes, which have the properties of protecting the body. Their higher levels in animals that have been given large amounts of iodine citrate for a long time may indicate a stimulating effect of the supplement on the immunobiological reactivity of the rabbit body.

The use of iodine citrate did not affect the significant changes in creatinine content in the blood of rabbits. Its levels were within physiological parameters, and the fluctuations were lower or higher relative to the control. Such changes indicate the physiological course of metabolic processes in the body of rabbits and the absence of negative effects from the applied amounts of the supplement.

The concentration of urea in the blood of rabbits of the experimental groups did not significantly change compared to the control, the differences were noted at the trend level. This may indicate that the compound used does not significantly affect the course of the body's metabolic processes involved in changes in the urea content.

Calcium metabolism in the body of rabbits has physiological features. First, it is a necessary macronutrient in the diet of rabbits for the course of physiological functions (structural, enzyme, signal). Second, excess calcium in the body is easily eliminated from the blood through the urinary excretion system (Vidal *et al.,* 2020). Drinking different amounts of iodine citrate to rabbits after weaning resulted in an insignificant increase in the level of total calcium in the blood during the study (Table 3).

***Table 3**. Total calcium and inorganic phosphorus content by drinking different amounts of iodine citrate (M±m, n=6)*

Indicator	Group	Research periods			
		preparatory, 40th day of life	experimental (age/day of drinking supplements)		
			58/18	83/43	96/56
Total calcium, mmol/l	C	3.3±0.17	3.0±0.34	3.1±0.22	3.3±0.27
	E-I	3.0±0.36	3.5±0.28	3.0±0.51	3.6±0.10
	E-II	3.1±0.08	3.7±0.63	3.8±0.09*	3.4±0.16
	E-III	3.5±0.18	3.8±0.64	3.5±0.20	3.5±0.12
	E-IV	3.2±0.51	3.9±0.37	3.4±0.56	3.4±0.22
Inorganic phosphorus, mmol/l	C	1.3±0.25	1.2±0.31	1.3±0.18	1.2±0.12
	E-I	1.2±0.24	1.3±0.33	1.5±0.51	1.4±0.29
	E-II	1.5±0.12	1.4±0.42	1.4±0.62	1.9±0.23*
	E-III	1.4±0.58	1.5±0.41	1.8±0.62	1.8±0.10**
	E-IV	1.5±0.17	1.8±0.32	1.7±0.57	1.7±0.17*
Calcium: Phosphorus	C	2.53:1	2.50:1	2.38:1	2.75:1
	E-I	2.50:1	2.69:1	2.01:1	2.57:1
	E-II	2.06:1	2.64:1	2.71:1	1.78:1
	E-III	2.50:1	2.53:1	1.94:1	1.94:1
	E-IV	2.13:1	2.16:1	2.00:1	2.02:1

It should be noted that the total calcium content in the blood of rabbits of the second experimental group exceeded the control by 22.5% only on the 43rd day of the study. The obtained results of the probable content and tendency to increase the level of total calcium in the blood of rabbits may be the reason for the use of iodine citrate; however, the length of time and different amounts of iodine citrate affected the assimilation of calcium from the forage of the diet. The results support literature sources that provide examples of elevated blood calcium levels due to the use of organic iodine in the rabbit diet (Reda *et al.*, 2020).

The involvement of P in the metabolism of rabbits has been understudied. Inorganic phosphorus is important in cell metabolism, but its involvement in the processes of bone calcification along with calcium is crucial. These two elements interact in transformation of the rabbit's cartilage skeleton into bone tissue after birth (Agedeson *et al.,* 2021). Feeding the iodine citrate compound to rabbits increased the absorption of phosphorus from the diet feed on the 18th and 43rd days of the study, although the results were at the level of the trend relative to the control. However, long-term drinking of the supplement resulted in other changes. Thus, the content of inorganic phosphorus in the blood of rabbits of the II, III and IV experimental groups was respectively higher by 5.8%, 5.0% and 4.1% on the 56th day of the study compared to the control group of animals. The obtained changes in the level of phosphorus in the blood of rabbits can indicate the influence of both the amount of the applied organic iodine compound and the duration of its consumption in the diet. Longer use of the supplement, for 56 days, to a greater extent ensured the supply of iodine to the body and contributed to its accumulation. Minor changes on the verge of a higher trend can be explained by the active metabolism in the body of fast-growing young animals and the rapid use of this element for metabolism.

An important indicator in providing the body with calcium and phosphorus is their ratio. Drinking iodine citrate from 40 to 58 days of life to rabbits affected changes in the blood of experimental animals in relation to the control with the ratio of calcium to phosphorus in the range of 2.16-2.69:1, on the 43rd day — 1.94-2.71:1, on the 56th day of the study 1.78-2.75:1. The obtained results of the study indicate an active absorption of calcium in the body at the first and second stages of the study and a high level of phosphorus at the final period of the experiment, which prevailed in animals of the experimental groups II-IV, which used large amounts of iodine citrate.

Therefore, added drinking of iodine citrate in a larger number of rabbits of experimental groups II–IV after weaning was affected by positive probable changes in metabolic processes, namely haematopoiesis, resistance, and assimilation of Calcium and Phosphorus compared to the control.

CONCLUSIONS

1. Added drinking of iodine citrate to rabbits after weaning at the rate of 2.5 μg I/l of water (Group I) was marked by the smallest changes in their blood, with the sole increase in albumin levels by 5.5% on the 43rd day of the study compared to the control.

2. Drinking iodine citrate to rabbits from the 40th day of life in the amount of 3.75 μg I/l of water (Group II) resulted in a significant increase in the number of erythrocytes and the level of haemoglobin in their blood, relative to the control, by 26.5% and 28.5%, and 31.0% and 30.6%, on the 43rd and 56th days, respectively; haematocrit – by 16.6% on the 56th day; total calcium – by 22.5% on the 43rd day; inorganic phosphorus – by 5.8% on the 56th day of the study; albumin – by 6.8%, 8.0%, 9.5% during the study.

3.The use of iodine citrate at the rate of 5.0 μg I/l of water (III experimental group) was characterised by a higher level of erythrocytes by 17.0%, 34.0%, and 36.6%; haemoglobin – by 26.4%, 34.1%, and 33.0%; haematocrit – by 17.1%, 20.0%, and 22.8%; albumin – by 6.1%, 4.6%, and 9.5%; and inorganic phosphorus – by 5.0% on the 56th day of the study compared to the control.

4.The use of the largest amount of 7.5 μg I/l of iodine citrate water (Group IV) was noted in the blood of rabbits, compared to the control, with higher indicators: erythrocytes – by 18.7%, 27.0%, and 31.2%; haemoglobin – by 30.3%, 39.6%, and 36.2%; haematocrit by 26.4%, 29.4%, and 23.5%, albumin – by 4.5%, 2.7%, 7.3% on the 18th, 43rd, and 56th days of the experiment and inorganic phosphorus by 4.1% on the 56th day of the study.

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Параметри крові кролів за випоювання різних кількостей йоду цитрату

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Анотація. У раціоні кролів повністю не з'ясована потреба у Йоді, хоча деякі комерційні раціони застосовують його у різних кількостях, не маючи наукового обґрунтування. Основною ціллю експерименту було встановити дію застосованих кількостей органічної сполуки йоду, виготовленої методом нанотехнології – йоду цитрату на параметри крові кролів після відлучення з 40 до 96 доби життя. Експериментальні дослідження були проведенні в умовах віварію наукової установи – Інститут біології тварин НААН м. Львів на 30 кролях породи Термонська. У контрольній та дослідних групах була однакова кількість, по 6 тварин, з яких 3 самці і 3 самиці. Молодняк кролів контрольної групи утримувався на стандартному гранульованому комбікормі й воді без обмеження. На відміну від контролю тварини I, II, III і IV експериментальних тварин додатково отримували, стосовно розчин йоду цитрату у кількості 2,5; 3,75; 5,0 і 7,5 мкг/л води. Визначення показників крові проводили на 40 добу життя (підготовчий період) та на 18-ту, 43-тю і 56-ту доби застосування добавки йоду цитрату. Дослідженнями встановлено вищу кількість еритроцитів та концентрацію гемоглобіну у крові кролів II групи ($P \leq 0,05$) на 43-тю і 56-ту добу; III групи ($P \leq 0,05$) та IV групи ($P \leq 0,05$-$0,01$) на 18-ту, 43-тю і 56-ту добу дослідження. Величина гематокриту крові кролів II групи була відповідно вищою на 16,6 % на 56-ту добу; III групи на 17,1 %; 20,0 % і 22,8 %, а у IV групі на 26,4; 29,4 і 23,5 % на 18-ту, 43-тю і 56-ту добу дослідження. Вміст альбуміну в крові кролів I групи був вищим відповідно на 4,1 % на 43-тю добу; II групи на 6,8 %; 8,0 %; 9,5 %; III групи на 6,1 %; 4,6 %; 9,5 %; IV групи на 4,5 %; 2,7 %; 7,3 % на 18-ту, 43-тю і 56-ту добу дослідження. Вміст загального кальцію у крові кролів II групи перевищував контрольну на 22,5 % на 43 добу, рівень неорганічного фосфору у крові кролів II, III і IV груп був відповідно вищим на 5,8 %, 5,0 % і 4,1 % на 56 добу дослідження порівняно з контролем

Ключові слова: наносполука, метаболізм, еритроцити, кальцій, фосфор

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Accumulation of ^{137}Cs by Thallus of Epiphytic Lichen *Hypogymnia physodes* (L.) Nyl on Different Trunk Height in Pine Stands

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Abstract. Lichens are considered by researchers as bioindicators of environmental pollution by artificial radionuclides, including ^{137}Cs. One of these bioindicator species is epiphytic lichen *Hypogymnia physodes* (L.) Nyl, the use of which for radioecological monitoring can be modified by several factors: tree species, placement on the tree (branches – trunk), height of sampling, etc. The purpose of this study was to investigate the specific activity of ^{137}Cs in thalli of hypogymnia in pine stands: on trunks of *Pinus sylvestris* L. and *Betula pendula* Roth at different heights of sampling in 3 height ranges: 0-65, 65-130, and 130-195 cm, and to analyse the intensity of radionuclide accumulation in the "lichen thallus – tree bark" link for both tree species in all height ranges. The study was conducted in August 2021 in the Korosten district of the Zhytomyr Oblast, Zhytomyr Polissia, on 4 test plots, in the Drevlianskyi nature reserve, mainly in middle-aged pine stands with an admixture of birch, where 130 samples of soil, tree bark, and lichen were taken. Specific activity of ^{137}Cs in the samples was measured using a SEG-001 "AKP-s"-150 gamma-ray spectrometer with a BDEG-20R2 scintillation detector (NaI(Tl). It was demonstrated that the content of ^{137}Cs in the thalli of *Hypogymnia physodes* at different altitude ranges did not differ statistically significantly at the 95% confidence level in all test plots on pine. A preliminary conclusion was made on the possibility of sampling *Hypogymnia physodes* thalli on pine trunks in the height range of 0-195 cm; however, for the convenience of sampling, it is recommended to perform sampling within 130-195 cm. It has been proven that both the specific activity of ^{137}Cs in *Hypogymnia physodes* thalli and the intensity of ^{137}Cs accumulation in the chain "Hypogymnia physodes — tree bark" are approximately 2 times higher on pine compared to birch. It was found that on a birch, the content of ^{137}Cs in lichen between the height ranges of 0-65 and 65-130 cm, and 0-65 and 130-195 cm differs significantly at the 95% confidence level; therefore, it is recommended to sample *Hypogymnia physodes* on a birch in the range of 65-130 cm

Keywords: *Pinus sylvestris* L., *Betula pendula* Roth, deciduous lichen, tree bark, accumulation coefficient, specific activity, radionuclide

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INTRODUCTION

Lichens, as symbiotic organisms with an atmospheric feeding strategy, have long been considered by researchers as biological indicators of environmental pollution by a wide range of pollutants found in the air (Ferry *et al.,* 1973; Bargagli *et al.,* 1991; Koroleva & Revunkov, 2017), and as convenient test objects for their monitoring (Richardson, 1994; Shukla *et al.,* 2014), including radioecological ones (Seaward, 1995; Biazrov, 2005; Kondratiuk, 2008).

From the late 1950s to the present, lichens have also been used to monitor radioactive contamination of various isotopic compositions and sources of entry into the biosphere. Radioecologists have demonstrated the high efficiency of using lichens to monitor global radionuclide precipitation as a result of nuclear weapons testing in the open earth environment (Eberhardt, 1964; Nevstrueva *et al.,* 1967), as well as migrations of technogenic radionuclides, primarily ^{137}Cs, food chains, e.g., "lichen – reindeer – human" (Tuominen & Jaakkola, 1973; Mattsson, 1975); in the monitoring zone around nuclear power plants during their regular operation in the Nordic countries (Ingemansson et al., 1981) and the former Soviet Union (Nifontova & Kulikov, 1981; Nifontova & Kulikov, 1984; Bossew *et al.,* 2000), as well as after nuclear accidents, the largest of which is Chernobyl. Notably, lichens are characterised by high resistance to a wide range of pollutants, including radionuclides (Richardson, 1994; Biazrov, 2005; Suno *et al.,* 2021).

To monitor the radioactive fallout of ^{137}Cs after the Chernobyl disaster, the researchers used as test objects different types of lichens of different morphological structure – leafy, bushy, powdery, crusty, etc., as well as of different ecological and topical groups – epiphytic, epigeal, epilithic and others (Biazrov, 2005). The choice of indicator species in these studies was largely determined by the natural conditions of the territory and the ability to select the required number of lichen thalli of a particular species for the analysis of ^{137}Cs content in samples and getting a representative sample. The researchers recognised *Hypogymnia Physodes* (L.) Nyl, which belongs to the *Parmeliaceae* family (hereinafter – hypogymnia), as one of such indicator species. It is an epiphytic leafy lichen characterised by a wide geographical range (forests of the boreal and temperate zones of the North hemisphere), with a considerable ecological amplitude, grows on the trunks and branches of many types of trees, including Scots pine (*Pinus sylvestris* L.) (hereinafter – pine) and silver birch (*Betula pendula* Roth) (hereinafter – birch), which are common in Ukrainian Polissia and Forest Steppe.

The advantages of this species of lichen when used as a test object are as follows: ease of identification in the field; the formation of multi-year macroscopic thalli available for observation and sampling throughout the year; growth in large numbers on tree trunks up to 2 m high; relatively insignificant dissection of the thalli, which allows measuring their area quite accurately; the convenience of sampling thallium samples, which are easily separated from the substrate – tree bark, branches, dead wood, etc.; the availability of a methodology for estimating the age of a particular thallus and its annual growth; direct absorption of ^{137}Cs from dry (dust) and wet (rain, snow) aerial precipitation, as well as crown and trunk run-off, which can be parameterised; availability of special scales for quantifying biomonitoring results obtained with lichens (Cecconi *et al.,* 2019).

The purpose of this study was to identify the influence of the sampling height of the indicator species – the leafy epiphytic lichen hypogymnia on the content of ^{137}Cs in its thalli – to determine the optimal sampling height in the long-term monitoring of radioactive contamination of forest ecosystem components.

The task was to study the specific activity of ^{137}Cs in the hypogymnia thalli in pine stands: on the trunks of Scots pine and hanging birch at different sampling heights in 3 height ranges: 0-65 cm, 65-130 cm, and 130-195 cm; to analyse the intensity of radionuclide accumulation in the link "lichen thalli – tree bark" for both tree species in all altitude ranges.

The scientific originality of this study is that for the first time, statistically reliable data were obtained on the effect of the height of the hypogymnia sample selection on the content of ^{137}Cs in them, and the optimal height of the sampling was determined.

LITERATURE REVIEW

Before the Chernobyl disaster, the ^{137}Cs content in hypogymnia thalli was mainly determined by global radionuclide precipitation. On the territory of the Central Urals (1981), specific activity of ^{137}Cs in hypogymnia thalli ranged within 480-750 Bq·kg^{-1} (Nifontova, 1998); on the territory of Lower Austria at an altitude of 720 m above sea level (1981) – 115-200 Bq·kg^{-1} (Eckl *et al.,* 1984), in northern Greece (1985) – 130 Bq·kg^{-1} (Sawidis *et al.,* 1997).

The Chernobyl disaster radically changed the levels of anthropogenic radionuclides in the biosphere, which found a clear imprint in specific activity of ^{137}Cs in lichen thalli, including hypogymnia. According to L.G. Biazrov (2005), the specific activity of ^{137}Cs in lichen thalli in the exclusion zone of the Chernobyl Nuclear Power Plant in 1986 increased by 10^2-10^4 times compared to pre-accident levels. However, even at a considerable distance from the Chernobyl NPP, namely along the western trail of emergency radioactive fallout in 1986, the specific activity of ^{137}Cs in hypogymnia thalli increased considerably: in Poland – by 10-100 times (up to 36.6 kBq·kg^{-1}) (Seaward et al., 1988), in Romania (Carpathians) – about 100 times (up to 88-211 kBq·kg^{-1}) (Bartok & Mocsy, 1990). In 1986, after the Chernobyl accident in Germany (Bavaria), the specific activity of the

mentioned radionuclide in hypogymnia thalli reached 9.6 kBq·kg^{-1} (Heinrich,1987), in Austria at different altitudes of the Alps – from 11-13. 2 kBq·kg^{-1} (Hofmann *et al.,* 1993) to 79.6 kBq·kg^{-1} (Heinrich, 1987), in central Norway – 8.5-38.8 kBq·kg^{-1} (Steinnes & Njastad, 1993), in the Urals, near the location of the Beloyarsk NPP – 15-25 kBq·kg^{-1} (Nifontova & Kulikov, 1990). Sharp increase in the specific activity of ^{137}Cs was also observed in hypogymnia thalli after the Fukushima NPP accident (Dohi *et al.,* 2021).

In Ukraine, after the Chernobyl accident, the levels of ^{137}Cs content in lichen thalli, including hypogymnia, have also been studied. However, these studies were fragmented, being conducted in different years, different biotopes, using different methods, and under different radiation conditions, so the results obtained are difficult to compare. O.B. Blum (2001) cited data that in 1991, the specific activity of ^{137}Cs in the hypogymnia thallus in the 5-km zone of the Chernobyl NPP reached 470-1,061 kBq·kg^{-1}, and 60 km from the accident unit – 1,253-1,631 Bq·kg^{-1}. In 2020, in Zhytomyr Polissia, in a wet pine forest (B3) with a soil pollution density of 138.99 ± 11.091 kBq·m^{-2}, the specific activity of ^{137}Cs in the hypogymnia thalli on pine trunks was 14.7±0.80 kBq·kg^{-1}, and in dry lichen barren (A1) at 17.7± 0.68 kBq·m^{-2} – 954±89.7 Bq·kg^{-1} (Pavlenko & Orlov, 2020).

However, when lichens are used in forest biogeocoenoses as test objects of radioecological monitoring, there are several factors that can considerably modify the results of observations, e.g., the specific activity of ^{137}Cs in hypogymnia thalli, which should be considered in the process of selecting lichen samples (Orlov & Krasnov, 2007). Thus, for epiphytic leafy lichens, it was demonstrated that the content of heavy metals increases from the periphery of the thallus to its centre, i.e., it is maximal in the oldest parts (Seaward, 1980; Wang *et al.,* 1997; Nimis *et al.,* 2001). Therefore, these researchers proposed for biomonitoring of heavy metals to use thalli of foliaceous lichens in a certain size range, which generally corresponds to their certain age. Researchers F. Gailey & O. Lloyd (1986) suggested using hypogymnia thalli with a diameter of 0.8 to 2 cm. The Italian monitoring protocol for heavy metals and radionuclides includes the sampling of not the whole thalli of leafy lichens, but only their peripheral parts. According to the researchers, this part of lichens more accurately characterises the content of pollutants in the air as of the current period (Nimis et al., 2001).

Among the modifying factors of the content of atmospheric pollutants, including radionuclides, in the thalli of epiphytic lichens, the researchers attributed the location of the thalli on a certain part of the tree (Wang *et al.,* 1997). According to their data, the content of radionuclides in the same species of lichen on tree trunks was 2-3 times lower compared to a similar indicator obtained for lichen on branches in the tree crown.

According to the results of the analytical review, the authors of this paper did not find any publications on the influence of the height of the hypogymnia sample selection on the content of ^{137}Cs in it.

MATERIALS AND METHODS

The study was conducted in August 2021 in the Korostensky District of Zhytomyr Oblast. Four trial plots were laid out in the Narodytskyi branch of the Drevlianskyi Nature Reserve, their brief characteristics are presented in Table 1.

***Table 1**. Brief description of test areas*

Test area No. (block/ allocation)	Geographical coordinates	Stand composition/ origin	Age, years	Height, m	Diameter, cm	Density	Forest type	Quality class	Density of soil contamination ^{137}Cs, kBq·m^{-2}
TA-1 (11/5)	51°10'5410"N 29°06'1315"E	10 Scots pine/artificial	52	19	23	0.94	B_2OP	I	133.4±8.92
TA-2 (94/2)	51°13'6449"N 29°07'2946"E	10 Scots pine, ind. Silver birch/artificial	56	16	20	0.95	A_2P	II	113.1±9.77
TA-3 (98/3)	51°14'1920"N 29°13'0947"E	10 Scots pine, ind. Silver birch/natural	91	24	34	0.80	A_2P	II	198.6±6.93
TA-4 (27/4)	51°10'3220"N 29°06'2738"E	10 Scots pine, ind. Silver birch/artificial	61	18	22	0.92	A_2P	II	158.2±5.16

The data in Table 1 show that the test areas were laid out in the predominant forest types of the Zhytomyr Polissia – fresh pine forest (A_2P) and fresh oak-pine subforest (B_2OP), were highly dense (0.80-0.95), were described by considerable productivity – I-II quality classes. In all areas, the coenosis of pine forest with green moss (*Pinetum hylocomiosum*) was represented. The density of ^{137}Cs soil contamination in the experimental areas was in the range of 113.1-198.6 kBq·m^{-2}.

On each trial area, 3 pine trees were found, and, if available, birch trees close to the average. Their trunks were marked with a white cord in the height ranges: 0-65 cm, 65-130 cm, and 130-195 cm (Fig. 1). From each height range, samples of hypogymnia thalli were taken

evenly over the entire surface of the trunk, they were carefully cleaned from the bark, and samples of the upper layers of the bark of the tree were taken from the same ranges. In the projection of the crown of each of the trees under study, according to the standard method (SOU 74.14-37-425:2006, 2006), soil samples were taken – with a cylindrical drill, 5 cm in diameter, without forest litter, to a depth of 20 cm, in 5 repetitions, after which these samples were mixed, and an aliquot was taken – a collective soil sample for radiation studies, with a volume of 1,000 cm^3.

Figure 1. *Marking of the pine trunk into height ranges for sampling*

In the measurement laboratory of the Polissia National University, hypogymnia, bark and soil samples were dried at a temperature of +80°C for 96 hours, after which the hypogymnia and bark samples were ground on an LMT-2 laboratory mill, and the soil – on a PRH-1 sample preparation machine. In the laboratory of radiology of the Polissky branch of Ukrainian Research Institute of Forestry and Forest Melioration, the soil was placed in Marinelli vessels with a volume of 1,000 cm^3, bark – in calibrated vessels with a volume of 135 ml ("Denta"), hypogymnia – in calibrated vessels with a volume of 80 ml (soil weighing bottle), after which they were weighed on analytical ANG-50C scales. The specific activity of ^{137}Cs in the samples was measured using a SEG-001 "AKP-S"-150 gamma spectrometer with a BDEG-20R2 scintillation detector (NaI(Tl). The relative measurement error of the mentioned indicator did not exceed 15%.

To evaluate the intensity of ^{137}Cs accumulation in the system "lichen thalli – tree bark", the accumulation coefficient (AC) (=proportionality coefficient) was determined – as the ratio of the specific activity of ^{137}Cs in the hypogymnia thalli (Bk·kg^{-1}) to the specific activity of ^{137}Cs in the tree bark (Bq·kg^{-1}) (Strand *et al.,* 2009).

Statistical analysis of the data was carried out in the Excel package using generally accepted methods of variational statistics (Lakin, 1973). Average values and simple statistics of the parameters under study for each of the height ranges were found on each trial area for 3 trees of the same breed, the statistical significance of the difference in the obtained data was determined according to the method of univariate analysis of variance per Fisher's test.

Notably, the use of hypogymnia as a bioindicator for detecting radioactive contamination has recently received little attention in the scientific literature. In this regard, the authors of this study chose a source base that describes the development of the use of hypogymnia in different periods, namely after the nuclear tests of the 1960s and 1970s and before the Chernobyl disaster, in the period between the accidents at the Chernobyl NPP and Fukushima, as well as after the Fukushima accident.

RESULTS AND DISCUSSION

The results of statistical processing of the specific activity values of ^{137}Cs in samples of hypogymnia and tree bark were grouped according to trial areas (Table 2). The analysis of these data shows important regularities, namely it is noticeable that in the test areas with higher levels of radioactive contamination of ^{137}Cs, the values of the specific activity of the mentioned radionuclide in the hypogymnia thalli were generally higher compared to less radioactively contaminated areas. Thus, on TA-3 with an average density of soil contamination of 198.6±6.93 kBq·m^{-2}, the content of radionuclide in the hypogymnia thalli on pine in the height range of 0-65 cm was 12,396±1,140.6Bq·kg^{-1}, and on TA-2 at 113.1±9.77 kBq·m^{-2} – 8,565±582.7 Bq·kg^{-1}.

***Table 2**. Statistical indicators of the specific activity of ^{137}Cs in the samples of hypogymnia and tree bark in the trial areas*

Sample type	Statistical indicators	Specific activity of ^{137}Cs in samples at different altitude ranges, Bq·kg^{-1}		
		h – 0-65 cm	h – 65-130 cm	h – 130-195 cm
		TA-1		
Hypogymnia on a pine tree	M±m	14,069±997.6	15,066±749.4	15,645±1,112.6
	Std	1,727.9	1,298.0	1,927.0
	V, %	12.29	8.62	12.32
	P, %	7.09	4.97	7.11
	min.	12,200	13,691	13,713
	max.	15,608	16,270	17,567
Pine bark	M±m	2,052±456.9	1,877±402.8	2,056±549.9
	Std	791.3	697.6	952.4
	V, %	38.56	37.16	46.32
	P, %	22.26	21.46	26.74
	min.	1,543	1,381	1,363
	max.	2,964	2,675	3,142
		TA-2		
Hypogymnia on a pine tree	M±m	8,565±582.7	11,049±874.6	10,615±851.1
	Std	1,009.3	1,514.9	1,474.1
	V, %	11.78	13.71	13.89
	P, %	6.80	7.92	8.02
	min.	7,402	9,397	9,000
	max.	9,215	12,373	11,888
Pine bark	M±m	1,887±171.9	1,724±216.4	1,534±101.4
	Std	297.7	373.9	175.7
	V, %	15.77	21.74	11.45
	P, %	9.11	12.55	6.61
	min.	1,571	1,340	1,350
	max.	2,162	2,089	1,700
Hypogymnia on a birch	M±m	3,934±450.4	4,022±231.2	3,919±103.3
	Std	780.1	400.4	179.0
	V, %	19.83	9.96	4.57
	P, %	11.45	5.75	2.64
	min.	3412	3761	3716
	max.	4,831	4,483	4,054
Birch bark	M±m	1,986±394.2	1,381±178.8	976±60.0
	Std	682.8	309.6	104.0
	V, %	34.39	22.43	10.65
	P, %	19.85	12.95	6.15
	min.	1,204	1,027	886
	max.	2,466	1,603	1,090
		TA-3		
Hypogymnia on a pine tree	M±m	12,396±1,140.6	14,797±1,102.9	14,099±1,853.6
	Std	1,975.6	1,910.3	3,210.5
	V, %	15.94	12.91	22.77
	P, %	9.20	7.45	13.15
	min.	10,862	12,856	11,878

Table 2, Continued

Sample type	Statistical indicators	Specific activity of ^{137}Cs in samples at different altitude ranges, Bq·kg^{-1}		
		h – 0-65 cm	h – 65-130 cm	h – 130-195 cm
		TA-1		
	max.	14,625	16,675	17,780
Pine bark	M±m	2,395±251.3	2,889±368.1	3,262±475.8
	Std	435.3	637.6	824.1
	V, %	18.18	22.07	25.26
	P, %	10.50	12.74	14.59
	min.	1,893	2,155	2,603
	max.	2,673	3,306	4,186
Hypogymnia on a birch	M±m	5,957±195.8	4,898±210.3	4,032±224.5
	Std	339.1	364.3	388.9
	V, %	5.71	7.44	9.64
	P, %	3.30	4.29	5.57
	min.	5,692	4,577	3,690
	max.	6,324	5,294	4,455
Birch bark	M±m	1,959±538.5	1,401±356.6	991±98.2
	Std	932.7	617.6	170.1
	V, %	47.62	44.07	17.16
	P, %	27.49	25.45	9.91
	min.	1,241	791	808
	max.	3,013	2,026	1,144
		TA-4		
Hypogymnia on a pine tree	M±m	9,881±842.2	12,265±1,031.4	11,747±1,299.1
	Std	1,458.8	1,786.5	2,250.2
	V, %	14.76	14.57	19.16
	P, %	8.52	8.41	11.06
	min.	8,256	10,219	9,545
	max.	11,077	13,516	14,042
Pine bark	M±m	2,188±184.0	1,844±237.5	1,623±125.3
	Std	318.8	411.4	217.1
	V, %	14.57	22.31	13.38
	P, %	8.41	12.88	7.72
	min.	1823	1411	1,373
	max.	2409	2230	1,771
Hypogymnia on a birch	M±m	3,645±127.2	3,925±147.0	3,977±39.7
	Std	220.3	254.6	68.7
	V, %	6.04	6.49	1.73
	P, %	3.49	3.75	1.00
	min.	3,412	3,738	3,922
	max.	3,850	4,215	4,054
Birch bark	M±m	1,878±302.1	1348±129.2	1,018±39.7
	Std	523.3	223.8	68.8
	V, %	27.86	16.60	6.76
	P, %	16.09	9.58	3.90
	min.	1,288	1093	953
	max.	2,287	1,512	1,090

Note: *M±m is the average arithmetic value with an error; Std is the standard square deviation; V is the variation coefficient; P is the relative error of the average arithmetic value (accuracy of the experiment); min., max. are the minimum and maximum value*

Data in Table 2 suggests that in all trial areas on the pine and on the birch, the specific activity of ^{137}Cs in the hypogymnia thalli varied quite slightly (V<20%) within each height range (Lakin, 1973). Thus, on a pine tree in the height range of 0-65 cm, the variation coefficient of the specific activity of ^{137}Cs in the hypogymnia thalli ranged from 11.78 to 15.94%, and the accuracy of the experiment was high, within 6.80-9.20%. A similar pattern was also observed in the remaining height ranges on pine. On the birch, in the height range of 0-65 cm, the variation coefficient of the specific activity of ^{137}Cs in the hypogymnia thalli was also low and was within 5.71-19.83% with 3.30-11.45% accuracy of the experiment. Like pine, birch had a similar distribution in the rest of the altitude ranges.

The significant values of the specific activity of ^{137}Cs in the thalli of hypogymnia, which grew on a pine tree, attract attention. At TA-1, TA-3 and TA-4, at almost all height ranges, the content of the mentioned radionuclide in the hypogymnia thalli exceeded 10 kBq·kg^{-1} – the level of contamination of solid radioactive waste from ^{137}Cs (Order of the Ministry of Healthcare of Ukraine No. 54, 2005) with relatively low values of radioactive contamination of the territory 133.4-198.6 kBq·m^{-2} (3.44-5.09 Ci·km^{-2}). This suggests that hypogymnia is an intensive accumulator of ^{137}Cs from aerial fallout, which correlates well with published data from other researchers (Richardson, 1994; Kondratiuk, 2008; Anderson *et al.*, 2022).

Notably, in all trial areas where pine and birch grew (TA-2, TA-3 and TA-4), the specific activity of ^{137}Cs in the hypogymnia thalli on birch at all height ranges was significantly lower compared to the pine thalli. On TA-2 in the height range of 0-65 cm, the mentioned indicator on the birch was equal to 3,934±450.4 Bq·kg^{-1}, and on pine – 8,565±582.7 Bq·kg^{-1}; in the height range of 65-130 cm, the values were equal to 4,022±231.2 and 11,049±874.6 Bq·kg^{-1}; in the height range of 130-195 cm – 3,919±103.3 and 10,615±851.1 Bq·kg^{-1}, respectively. The results of the univariate analysis of variance showed that in all sample areas, the difference in the average values of ^{137}Cs content in the hypogymnia thalli on the pine and on the birch differed substantially at the 95% confidence level: on TA-2 – $F_{fact.}$=39.53–61.09> >$F_{0.95}$=7.71, p=0.001-0.003; on TA-3 – $F_{fact.}$=29.07-77.73> >$F_{0.95}$=7.71, p=0.001-0.006; on TA-4 – $F_{fact.}$=35.74-64.08> >$F_{0.95}$=7.71, p=0.001-0.004.

It is also important to compare the average values of the ^{137}Cs content in hypogymnia thalli at each trial area on pine in all height ranges (Fig. 2). The analysis of these data shows that the amount of ^{137}Cs content in the hypogymnia thalli varied in different height ranges on pine in different trial areas. On TA-1, a monotonous increase in the mentioned indicator was observed from 0-65 cm to 65-130 cm and furtherx– to 130-195 cm. In the rest of the test plots, an increase in the specific activity of ^{137}Cs was observed in the hypogymnia thalamus from 0-65 cm to 65-130 cm, followed by a decrease in the height range of 130-195 cm.

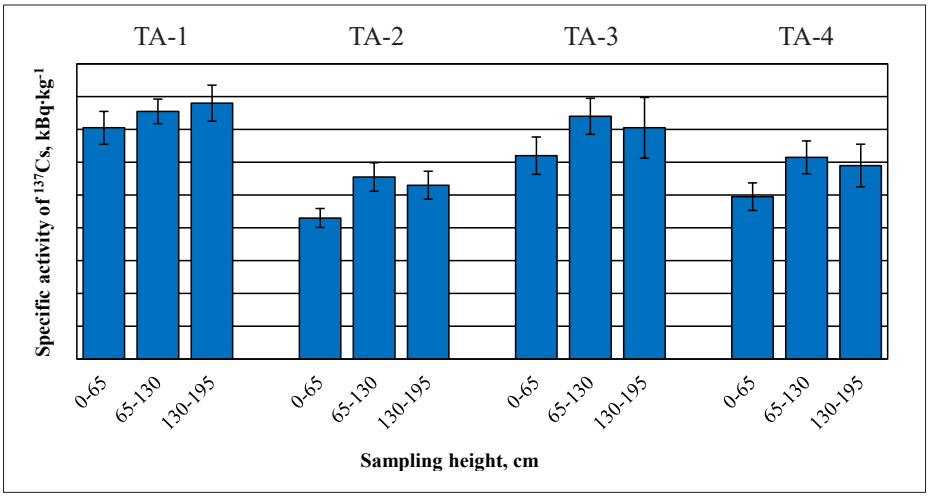

Figure 2. *The average values of the specific activity of ^{137}Cs in the hypogymnia thalli on the pine in the trial areas*

However, in most of the trial areas, the errors of the arithmetic mean of the indicator under study overlapped, and therefore it is important to assess the statistical significance of the difference in the content of ^{137}Cs in the hypogymnia thalli at different height ranges in each of the trial areas. Calculations showed that in all test areas on pine, the content of ^{137}Cs in hypogymnia thalli at different height ranges did not differ statistically significantly at the 95% confidence level: on TA-1 – $F_{fact.}$ = =0.08-2.60<$F_{0.95}$=7.71; on TA-2 – $F_{fact.}$=3.95-5.59<$F_{0.95}$=7.71; on TA-3 – $F_{fact.}$=0.61-2.29<$F_{0.95}$=7.71; on TA-4–$F_{fact.}$=0.10-3.20<$F_{0.95}$=7.71. Thus, it is legitimate to draw a preliminary conclusion about the possibility of selecting hypogymnia thalli on pine trunks in the height range of 0-195 cm; however, considering the greater convenience of sampling, the authors of this paper recommend performing the sampling in the height range of 130-195 cm.

Of considerable scientific interest is the assessment of the intensity of ^{137}Cs accumulation in the thalli

of hypogymnia on pine at different trial areas (Fig. 3). These data clearly indicate certain trends in changes in the average values of AC at different altitude ranges of pine. On TA-1, TA-2, TA-4, the average values of AC increase with height, and on TA-3 they increase within the height range of 0-65 cm and 65-130 cm and decrease above. However, considering the errors of the arithmetic mean, which in most cases overlap, the assessment of the statistical significance of the parameter under study is of considerable interest.

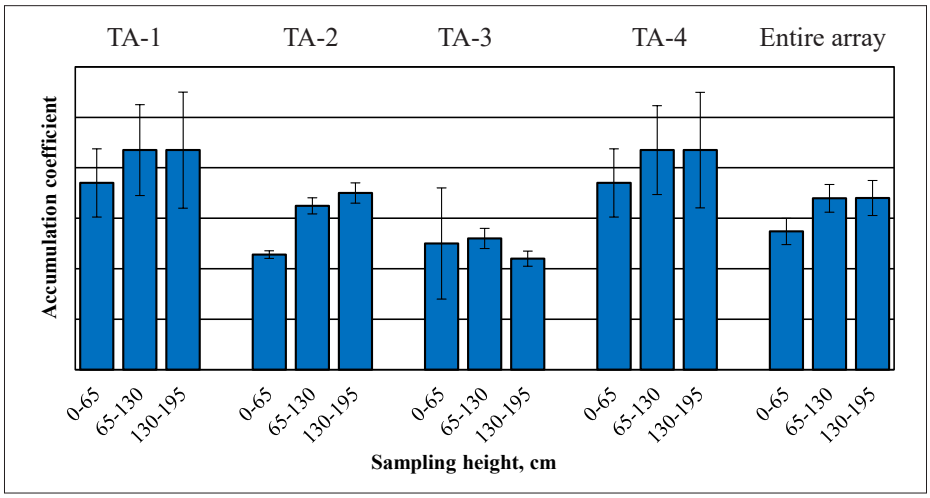

Figure 3. *Average AC values of ^{137}Cs in the link "hypogymnia thalli – pine bark" in different trial areas*

It was found that on TA-1, the average values of AC at different height ranges of pine did not differ statistically significantly at the 95% confidence level – $F_{fact.}$=0.01-0.35<$F_{0.95}$=7.71, and on TA-3 – $F_{fact.}$=0.03-0.80<$F_{0.95}$=7.71. However, on TA-2, the difference in the average values of AC was substantial at the 95% confidence level between the height ranges of 0-65 and 65-130 cm – $F_{fact.}$=30.56>$F_{0.95}$=7.71; p=0.005; in the ranges of 0-65 cm and 130-195 cm – $F_{fact.}$=34.59>$F_{0.95}$=7.71; p= 0.004; at the same time, there was no statistically significant difference between the ranges of 65-130 cm and 130-195 cm – $F_{fact.}$=0.80<$F_{0.95}$=7.71. On TA-4, a significant difference in the average values of AC is shown for all pairs of height ranges: 0-65 cm and 65-130 cm – $F_{fact.}$=34.61>$F_{0.95}$=7.71; p=0.004; in the ranges of 0-65 cm and 130-195 cm – $F_{fact.}$=10.64>$F_{0.95}$=7.71; p=0.03 and ranges of 65-130 cm and 130-195 cm – $F_{fact.}$=57.08>$F_{0.95}$ =7.71; p=0.002.

According to a similar scheme, hypogymnia was studied on the birch as well (Fig. 4). These data suggest that the specific activity of ^{137}Cs in the thalli of hypogymnia at different height ranges of birch in the trial areas changed differently. At TA-2, the values of the mentioned indicator at all height ranges were close – 3,919-4,022 Bq·kg^{-1}. On TA-4, a weak increase in the mentioned indicator was observed in the height ranges from 0-65 cm to 65-130 cm – 3,645-3,925 Bq·kg^{-1} and further in the height range of 130-195 cm – up to 3,977 Bq·kg^{-1}. Considering the overlap of the errors of the average values of the indicator under study on TA-2 and TA-4, between the height ranges on the birch, the specific activity of ^{137}Cs in the hypogymnia thalli did not differ statistically at the 5% level of significance: on TA-2 – $F_{fact.}$=0.00-0.08<$F_{0.95}$=7.71; on TA-4 – $F_{fact.}$=0.12-6.22<$F_{0.95}$=7.71. However, on TA-3, the difference of the mean values under study in all dispersion pairs was significant at the 95% confidence level: between the height ranges of 0-65 cm and 65-130 cm – $F_{fact.}$=13.07>$F_{0.95}$=7.71; p = 0.02; between the height ranges 0-65 cm and 130-195 cm – $F_{fact.}$=40.90>$F_{0.95}$=7.71; p=0.003; between the height ranges of 65-130 cm and 130-195 cm – $F_{fact.}$=7.92>$F_{0.95}$=7.71; p=0.05.

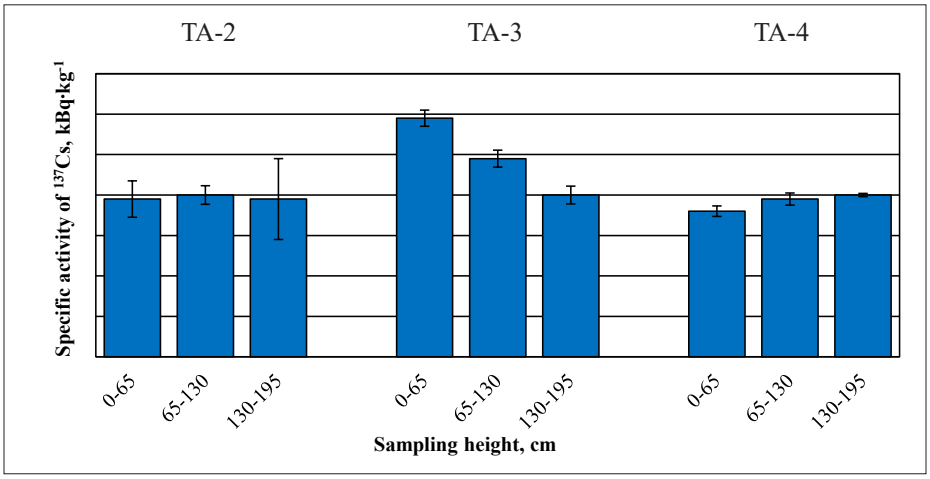

Figure 4. *Average values of the specific activity of ^{137}Cs in the hypogymnia thalli on the birch in the test areas*

Average values of the accumulation coefficient of ^{137}Cs in the link "hypogymnia thalli – birch bark" at all height ranges were calculated for the test areas where birch was present (Fig. 5). The data in this figure clearly show that a general trend was observed in all test areas on the birch – a monotonous increase in the average values of AC with height. For example, on TA-2, the average values of AC were as follows: in the height range of 0-65 cm – 2.1±0.43; in the height range of 65-130 cm – 3.0±0.34; in the height range of 130-195 cm – 4.0±0.16. It is of great interest that on several trial areas the difference in the average values of AC at different height ranges was statistically significant at the 95% confidence level: on TA-2 between the height ranges of 0-65 cm and 130-195 cm – $F_{fact.}$=17.10>$F_{0.95}$=7.71; p=0.01; between the height ranges of 65-130 and 130-195 cm – $F_{fact.}$=7.74>$F_{0.95}$=7.71; p=0.05; however, there was no statistically significant difference between the height ranges of 0-65 and 65-130 cm – $F_{fact.}$=2.43<$F_{0.95}$=7.71. Furthermore, a substantial difference in mean values was demonstrated at the 5% level of significance for all dispersion pairs of AC on TA-4 – $F_{fact.}$=10.64-57.08>$F_{0.95}$=7.71; p=0.001-0.03. On the other hand, on TA-3, there was no statistically significant difference in the average values of AC between all height ranges on the birch – $F_{fact.}$=0.20-0.68<$F_{0.95}$=7.71. Furthermore, the average values of AC were calculated for the entire array of data on birch for all height ranges (Fig. 4). Calculations showed that in the height range of 0-65 cm, the average value of AC in the link "hypogymnia thalli – birch bark" was equal to 2.5±0.35; in the height range of 65-130 cm – 3.6±0.33; in the height range of 130-195 cm – 4.0±0.16.

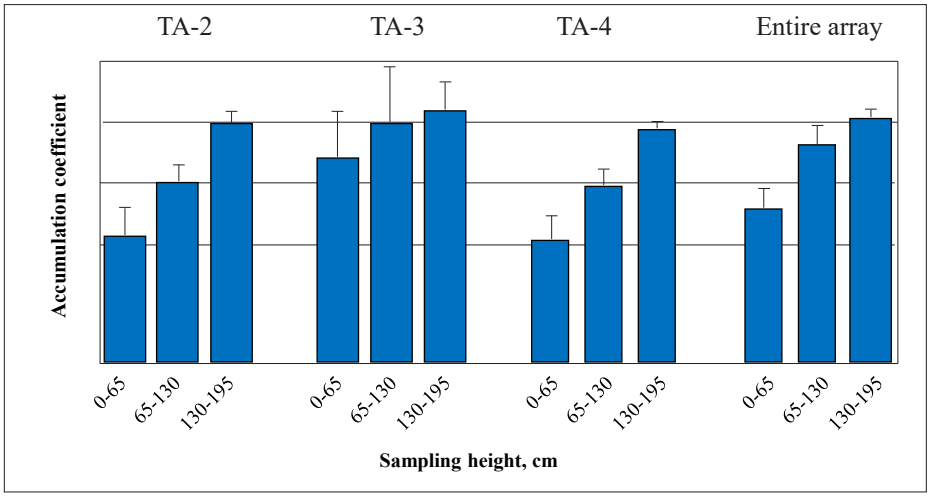

Figure 5. *Average AC values of ^{137}Cs in the link "hypogymnia thalli – birch bark" in different trial areas*

It was demonstrated that between the height ranges of 0-65 cm and 65-130 cm, there was a substantial difference at the 95% confidence level – $F_{fact.}$=4.96>$F_{0.95}$=4.49; p=0.04; between the height ranges of 0-65 cm and 130-195 cm – $F_{fact.}$=14.97>$F_{0.95}$=4.49; p=0.001; however, there was no statistically significant difference between the height ranges of 65-130 and 130-195 cm – $F_{fact.}$=1.26<$F_{0.95}$=4.49. Therefore, the authors of this paper recommend sampling the Hypogymnia physodes on the birch in the range of 65-130 m.

A comparison of the data in Figures 2 and 4 suggests that the intensity of ^{137}Cs accumulation in the link "hypogymnia thalli – tree bark" is considerably higher in pine than in birch. The difference in the average values of AC in the trial areas at different altitude ranges was as follows: TA-2 – 1.8-2.1 times; TA-3 – 1.1-1.5 times; TA-4 – 1.8-2.3 times. The likely reason for this is the lower acidity of pine bark (pH=3.0-3.1) compared to birch bark (pH=3.5-3.6) (Fojcik *et al.*, 2017). Pine bark acidifies the flow of trunk and crown run-off, while ^{137}Cs is leached from the microparticles of dust it carries. In birch, the acidification of run-off is less pronounced. The leached ^{137}Cs in a water-soluble form is absorbed by the hypogymnia thalli, which, thus, returns ^{137}Cs to the small (biological) cycle and prevents it from entering the soil – to the large (geological) cycle. Furthermore, the variation in the content of ^{137}Cs in the bark and hypogymnia thalli at different altitude ranges can be explained by the fact that the pH of the bark of both pine and birch at different altitudes can vary significantly (Grodzinska, 1976), causing the variation in the content of ^{137}Cs in components under study – both in tree bark and hypogymnia thalli.

The materials obtained in the trial areas, which represent the pine forests prevailing in Zhytomyr Polissia, expand the ideas about the ways of redistribution of ^{137}Cs in forest ecosystems, namely about the levels of accumulation of the mentioned radionuclide in the thalli of the known indicator species of epiphytic lichens – hypogymnia. This particular species was previously studied upon analysing the content of ^{137}Cs in the components of forest (Boyko & Orlov, 2012) and forest-swamp ecosystems (Orlov, 2021). Therewith, lichen sampling was always carried out on Scots pine trunks in a narrow height range – 120-150 cm. The results obtained in this paper proved that among all the components of the biota of the ecosystems under study, hypogymnia in terms of specific activity levels of ^{137}Cs

was inferior only to a part of the macromycete species, which provided the possibility of measuring this indicator in small samples of lichen with acceptable accuracy.

The authors of this paper consider the results of this study to be pilot, since they were obtained during one growing season. Statistically reliable substantiation of the optimal sampling height of hypogymnia on tree trunks for bioindication of radioactive contamination of forest ecosystems is not only of scientific, but also of essential practical importance, since the sampling height of this lichen and the tree organ from which its samples are taken can considerably affect the ^{137}Cs content in it, and, accordingly, on the results of long-term monitoring.

Prospects for further research are to confirm the obtained results on a larger statistical sample, in diverse types of forest vegetation conditions, in plantations of different species composition (pine, oak, birch, mixed) and of different ages.

CONCLUSIONS

1. The specific activity of ^{137}Cs in the hypogymnia thalli varied rather weakly in all test plots on the pine and on the birch – the coefficient of variation was less than 20%.

2. In all test areas, the values of the specific activity of ^{137}Cs in the hypogymnia thalli on the birch at all altitude ranges were considerably lower compared to the lichen thalli on the pine and differed substantially at the 95% confidence level.

3. In all test areas on pine, the content of ^{137}Cs in hypogymnia thalli at different altitude ranges did not statistically significantly differ at the 95% confidence level. This allowed drawing a preliminary conclusion about the possibility of sampling hypogymnia thalli on pine trunks in the height range of 0-195 cm; however, considering greater convenience, the authors of this paper recommend performing sampling on pine trees in the height range of 130-195 cm.

4. The average AC values of ^{137}Cs in the link "hypogymnia thalli – tree bark" throughout the data array were as follows: on pine, in the height range of 0-65 cm – 7.4±1.35; 65-130 cm – 8.7±1.76; 130-195 cm – 8.7±2.29; on the birch, in the height range of 0-65 cm – 2.5±0.35; 65-130 cm – 3.6±0.33; 130-195 cm – 4.0±0.16.

5. On TA-2 and TA-4 between the height ranges on the birch, the specific activity of ^{137}Cs in the thalli of hypogymnia did not differ statistically significantly at the 5% level of significance, on TA-3 the difference was significant between all height ranges.

6. A significant difference at the 95% confidence level was observed in the average AC values on the birch between the height ranges of 0-65 cm and 65-130 cm, and 0-65 cm and 130-195 cm, but it was absent between the ranges of 65-130 cm and 130-195 cm. Therefore, the authors of this paper preliminarily recommend sampling the Hypogymnia physodes on the birch in the height range of 65-130 cm.

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Акумуляція ^{137}Cs таломами епіфітного лишайника *Hypogymnia physodes* (L.) Nyl на різних висотах стовбура у соснових деревостанах

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Анотація. Лишайники розглядаються дослідниками як біоіндикатори забруднення навколишнього середовища штучними радіонуклідами, в т.ч. ^{137}Cs. Одним з таких видів-біоіндикаторів є епіфітний лишайник *Hypogymnia physodes* (L.) Nyl, використання якого для радіоекологічного моніторингу може модифікуватися рядом факторів: деревною породою, розміщенням на дереві (гілки – стовбур), висотою відбору зразків та ін. Метою досліджень було вивчити питому активність ^{137}Cs у таломах гіпогімнії у соснових деревостанах: на стовбурах *Pinus sylvestris* L. та *Betula pendula* Roth на різній висоті відбору зразків у 3-х діапазонах висот: 0–65, 65–130, 130–195 см та проаналізувати інтенсивність акумуляції радіонукліду у ланці «таломи лишайника – кора дерева» для обох деревних порід у всіх висотних діапазонах. Дослідження проведене у серпні 2021 р. у Коростенському районі Житомирської області, Житомирському Поліссі, на 4 пробних площах, у природному заповіднику «Древлянський», переважно у середньовікових соснових деревостанах з домішкою берези, де відібрано 130 зразків ґрунту, кори дерев та лишайника. Питому активність ^{137}Cs у зразках вимірювали з використанням гамма-спектрометра СЕГ-001 «АКП-С»–150 зі сцинтиляційним детектором БДЕГ-20Р2 (NaI(Tl). Продемонстровано, що на всіх пробних площах на сосні вміст ^{137}Cs у таломах Hypogymnia physodes на різних висотних діапазонах статистично достовірно не відрізнявся на 95 % довірчому рівні. Зроблено попередній висновок про можливість відбору таломів Hypogymnia physodes на стовбурах сосни у діапазоні висот 0-195 см, однак, для зручності відбору зразків попередньо рекомендуємо проводити його у діапазоні 130-195 см. Доведено, що, як питома активність ^{137}Cs у таломах *Hypogymnia physodes*, так і інтенсивність акумуляції ^{137}Cs у ланці «*Hypogymnia physodes* – кора дерев» є приблизно у 2 рази вищою на сосні порівняно з березою. Виявлено, що на березі вміст ^{137}Cs у лишайнику між висотними діапазонами 0–65 – 65–130 см та 0–65 – 130–195 см суттєво відрізняється на 95 % довірчому рівні, тому попередньо рекомендуємо відбір зразків *Hypogymnia physodes* на березі проводити у діапазоні 65–130 см

Ключові слова: *Pinus sylvestris* L., *Betula pendula* Roth, листуватий лишайник, кора дерева, коефіцієнт накопичення, питома активність, радіонуклід

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Assessment of the Influence of Weather Factors on the Quantitative Indicators of Sweet Cherry Fruits by Ridge Regression

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Abstract. Sweet cherries are a favourite stone crop among consumers of fruit products. At present, the demand for sweet cherries is growing, which encourages the expansion of the varietal range of crops with different ripening periods. The purpose of this study was to develop a mathematical model for predicting the formation of fruit and sweet cherry pyrene mass depending on weather factors and varietal characteristics. The study was conducted during 2008-2019 in the conditions of the Southern Steppe zone of Ukraine on 33 varieties of sweet cherries of early, medium, and late ripening periods. The average mass of the sweet cherry fruit over the years of research was 8.41 g, and the average mass of the pyrene was 0.56 g. Late-ripening sweet cherry varieties had the best fruit mass (7.27-12.18 g). According to the maximum average mass of the fruit, the varieties Kazka, Dilema, and Kosmichna were distinguished. Rubinova Rannia, Pervistok, Melitopol black and Krupnoplidna varieties had the lowest pyrene mass in sweet cherry fruits. In the group of early ripening, the best ratio of pyrene to fruit pulp was found in the Kazka variety, in medium-ripening varieties – Cordia, Perviystok, and Orion, in late-ripening varieties – Udivitelna, Krupnoplidna, and Prazdnichna. The smallest variability in sweet cherry fruit mass in the group of early-ripening varieties was detected in Sweet Erlise, in mid-ripening – Temp, and in late-ripening – Regina, while in pyrene mass – Rubinova Rannia, Vynka and Regina, respectively. Weather conditions had a dominant influence on the formation of fruit mass for all sweet cherry varieties under study, and varietal characteristics had a dominant effect on pyrene mass. The maximum influence on the formation of sweet cherry fruit mass of early varieties was provided by the indicator – the number of days with precipitation in May exceeding 1 mm, and for medium and late ripening varieties – the average monthly amount of precipitation in June. Decisive importance for the formation of pyrene mass in sweet cherry fruits of early ripening varieties was the average monthly amount of precipitation in May, in the middle ripening period – the average monthly amount of precipitation in June, in the late ripening period – the number of days with precipitation exceeding 1 mm in May

Keywords: pyrene mass, fruit mass, the ratio of pyrene to fruit pulp, variation of indicators, climatic conditions, regression model

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INTRODUCTION

A considerable role in solving the country's food security is played by the products of the horticultural industry, the main task of which is to meet the needs of the population with fresh fruit raw materials. Fruit products form an integral part of a full and balanced human diet. One of the key and favourite stone crops among consumers of fruit products is sweet cherries (Dziedzic *et al.,* 2017; Szpadzik *et al.,* 2019; Ivanova *et al.,* 2022). The popularity of this fruit crop is conditioned upon not only the prominent taste qualities of fruits with an attractive appearance (Cao *et al.,* 2015; Pereira *et al.,* 2020; Ivanova *et al.,* 2021a), but also upon the early ripening period (Kim *et al.,* 2005; Pérez-Sánchez *et al.,* 2008; Savchovska & Nesheva, 2021).

Sweet cherries are a valuable fruit from the Rosaceae family grown all over the world (Bieniek *et al.,* 2011; García-Montiel *et al.,* 2017; Avramidou *et al.,* 2021). Considering the biological features of growth and development, sweet cherries are grown in a moderately warm climate (Biško *et al.,* 2017; Bhat *et al.,* 2018; Bustamante *et al.,* 2021). On the territory of Ukraine, most sweet cherry plantations are concentrated in the southern region (Ivanova *et al.,* 2020; Shubenko *et al.,* 2021). Sweet cherry fruits begin to ripen from the third decade of May and open the period of consumption of high-quality fresh fruit (Serdyuk *et al.,* 2020; Vignati *et al.,* 2022).

The growth rate of global sweet cherry fruit production is constrained by the economic, environmental, and social challenges of modern times (Boubennec, 2019). This necessitates the search for ways to increase the competitiveness of sweet cherry products in the external and internal markets (Szpadzik *et al.,* 2019; Basile *et al.,* 2021; Bustamante *et al.,* 2021). The productivity of sweet cherry varieties is investigated according to many indicators, namely ripening and storage time, logistics, commercial qualities, content of biologically active substances, yield, the possibility of manufacturing processed products from sweet cherry fruits, etc. (Martino *et al.,* 2018; Szpadzik *et al.*, 2019; Ivanova *et al.,* 2021b).

M. Grandi et al. (2017) investigated the effect of sweet cherry fruit harvesting time on their taste. It is advisable to determine the onset of physiological ripeness of fruits on the tree and not reduce it to implement a marketing or commercial strategy. X. Zhang et al. (2020) presents the results of a study of the influence of sweet cherry fruit transportation conditions on the preservation of their quality indicators, as well as the dependence of the selling price on the quality of fruits, especially in express logistics. To reduce the quality losses of fresh sweet cherry fruits in express logistics, they proposed a dynamic monitoring and quality assessment system (DMQAS) based on multi-sensors. To extend the shelf life and transportation of sweet cherry fruits, scientists developed methods for their post-harvest processing and studied the content of biologically active components (Chockchaisawasdee *et al.,* 2016).

Research conducted in Southern Chile was devoted to quality management of sweet cherry fruit products (Bustamante *et al.,* 2021). Scientists evaluated the quality indicators of sweet cherry fruits, depending on the influence of foliar top dressing with potassium before harvesting and the condition of trees in a plastic shelter. An improvement in the quality of sweet cherry fruits of the Regina variety under the influence of potassium was established, depending on the season and region of cultivation.

The dynamics of accumulation of biologically active substances in fruits depending on the use of gibberellic, abscisic, and salicylic acids and glycine betaine was investigated on two varieties of sweet cherry "Skeena" and "Sweetheart" (Correia *et al.,* 2020). Other scientists have also researched the variation of the content of biological substances in sweet cherry fruits depending on varietal characteristics (Budak, 2017; Antognoni *et al.*, 2020). Features of formation of yield and quality of fruits of sweet cherry varieties "Ziraat 0900" and "Cordia" depending on the density of planting on the rootstock Gisela 6 were studied (Arsov *et al.,* 2020). The highest yield of the varieties under study was provided by planting schemes of 5x3.5 m. Scientists found that the mass and density of the collected fruits met the established standards and did not vary depending on the planting scheme. Seven new varieties of sweet cherry "Cetăţuia", "Cătălina", "Bucium", "Golia", "Maria", "Ştefan", and "Tereza" were investigated in the conditions of the North-East of Romania (Sîrbu *et al.,* 2012). A. Hajagos et al. (2012) reported the effect of rootstock on fruit consumption value, appearance, and taste. Thus, depending on the choice of rootstock, the mass of fruits, their hardness, as well as the content of sugar and organic acids changed. The dependence of the formation of fruit mass on the rootstock and variety was noted in the studies of M.D. Pal et al. (2017).

It was established that the duration of the period from full flowering to ripening of fruits does not substantially affect their commercial quality and chemical composition. The quantitative composition of the biochemical parameters of sweet cherry fruits is substantially influenced by weather factors during the ripening period of fruits and genetic features of pomological varieties (Ivanova *et al.,* 2020; Serdyuk *et al.,* 2020; Shubenko *et al.,* 2021).

One of the indicators that determines the competitiveness of sweet cherry fruits is the average mass of the fruit and pyrene and the pyrene to pulp ratio (Pérez-Sánchez *et al.,* 2010; Maglakelidze *et al.,* 2017). According to research, the fruit mass of sweet cherry varieties is one of the key quality characteristics that affects the demand of fruit consumers (El Baji *et al.,* 2021; Michailidis *et al.,* 2019) and the price of products (Pérez-Sánchez *et al.,* 2010). It was found that the mass of sweet cherry fruits is substantially influenced by the genetic characteristics of the variety and the soil and climatic conditions of growing the crop (Corneanu *et al.,* 2020).

Among weather factors, vital indicators are temperature and moisture during the growing season of sweet cherries.

Considering the above, the study of the quality of fruits of sweet cherry varieties, which is associated with the technology of growing this crop, harvesting, selling, and further processing of fruits, constitutes a topical issue. The question of the influence of weather factors on the formation of fruit mass and pyrene in sweet cherry varieties of diverse ripening periods is still understudied. Usually, correlation-regression analysis methods are used to analyse the influence of weather factors on the quality and marketability of sweet cherry fruits (Ivanova *et al.,* 2021a). But, as correlation analysis of weather factors shows, there is a prominent level of correlation between individual factors, i.e., the multicollinearity effect. Under such conditions, using the least squares method to construct regression models is inefficient. In the case of multicollinear factors, regularisation methods should be applied. In the works of scientists (Ivanova *et al.,* 2021b) it was proposed to use the LASSO method upon analysing the degree of influence of factors. In this paper, it is proposed to build a regression model based on RIDGE-regression. Thus, the use of improved methods for predicting the influence of abiotic factors on the mass of fruits and pyrenes in sweet cherry fruits of different ripening periods in regions with hydrothermal indicators similar to the Southern Steppe zone of Ukraine is relevant.

Therefore, the purpose of this study was to develop a mathematical model for predicting the formation of fruit and pyrene mass in sweet cherry fruits of different ripening periods depending on weather conditions.

To fulfil *the purpose of this study*, the following tasks had to be solved:

– analyse weather conditions during the formation of sweet cherry fruits of different ripening periods;

– identify varieties of sweet cherries of different ripening periods during their consumer ripeness according to the maximum indicators of fruit mass and optimal values of pyrene mass;

– establish the correlation between the processes of fruit and pyrene mass formation and stressful weather factors;

– build mathematical models of the dependence of the mass of fruits and pyrenes on weather factors or varietal characteristics and analyse them to find the share of influence of each factor separately.

MATERIALS AND METHODS

The study was conducted on chernozem southern light loam soils in 2008-2019 in the agro-ecological conditions of the Southern Steppe subzone of Ukraine. Meteorological data from the Melitopol Meteorological Station of Zaporizhzhia Oblast (Ukraine) were used for the study. The climate of the research region is Atlantic continental, with hot temperature and insufficient humidity. The region is dominated by easterly and north-easterly winds, with an average wind speed of 3.7 m/s. The average annual air temperature varies from 9.1 to 9.9°C. The warmest months are July and August, with average monthly temperatures ranging from 20.5 to 23.1°C. The average annual sum of active temperatures from April to October is at 3,316°C. The region receives an average of 475 mm of precipitation per year. The average annual relative humidity in the region is 73%. Hydrothermal coefficient (HTC) according to G. T. Selyaninov is in the range from 0.22 to 0.77 (Ivanova *et al.,* 2022).

For the study, 33 cherry varieties were selected on mahaleb cherry rootstocks of three ripening periods: 7 early-ripening, 13 medium-ripening, and 13 late-ripening varieties (Fig. 1). The fruits of the sweet cherry varieties under study were selected in the gardens of the Melitopol District of the Zaporizhzhia Oblast. The technology of growing sweet cherries of all ripening periods in experiments was generally accepted for the Southern Steppe subzone of Ukraine. The scheme of planting sweet cherry trees in 2001 was according to the 5×3 m scheme. The interrows in cherry plantations were kept under black steam.

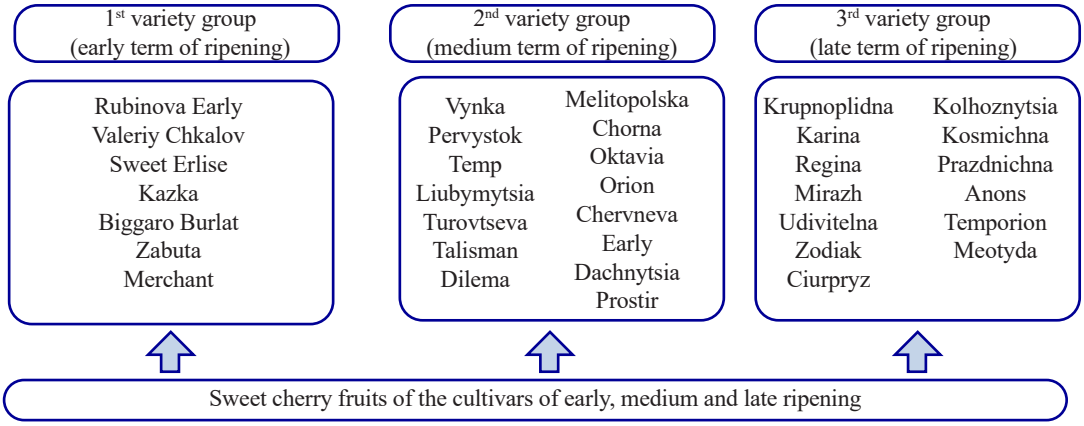

Figure 1. *Sweet cherry varieties of three ripeness groups were investigated*

During the period of consumer ripeness, samples (100 fruits) were taken from 3-5 typical trees for a certain pomological variety with an average fruiting intensity. Repeatability – three times. Samples were taken in 4 separate places of the tree crown. The selected fruits had to correspond in quality to the first commercial grade. All selected fruits were weighed and the mass of one fruit was determined by dividing the total mass by their number (100 pcs). After weighing the fruit sample, their pyrenes were removed. The resulting pyrenes were washed from the pulp and moisture was removed from their surface with filter paper. Next, the pyrenes were weighed and the average mass of one pyrene was determined.

By conducting a two-factor variance analysis, during the study, the expediency of predicting fruit mass, pyrene mass in sweet cherry fruits based on average values for a certain group of varieties was determined, and the factor (Factor A – climatic conditions of the year or Factor B – varietal characteristics) that has the greatest effect on accumulation of parameters under study in sweet cherry fruits, were identified.

The dependence of fruit and pyrene mass of sweet cherry varieties of three ripening periods on climatic factors was studied in the following stages:

Stage 1. Analysis of indicators of weather and climatic factors in the years of research.

Stage 2. Calculation of temperature indicators and humidification indicators.

Stage 3. Selection of weather factors that have a high-level correlation with the indicators under (fruit and pyrene mass).

Stage 4. Construction of regression models of fruit and pyrene mass dependence on weather factors that have a high-level correlation.

Stage 5. Comparative analysis of the degree of influence of selected weather factors on the fruit and pyrene mass.

Next, the authors considered each point of the algorithm in more detail. At Stage 1 of the algorithm, a database of weather factor indicators for the years of research was created. At Stage 2, the most significant temperature and humidity indicators were selected.

At Stage 3, weather and climate factors were selected that showed a significant level of correlation. For this purpose, the statistical hypothesis about the significance of the calculated correlation coefficients between the factors and the indicator under study was tested. The statistical hypothesis was tested according to the Student's t-test at a significance level of 0.05. Furthermore, factors were selected that are logically justified in terms of their impact on the indicators under study (fruit and pyrene mass) but did not show a high correlation with them. At Stage 4, a RIDGE regression model of the dependence of the indicator under study on those selected at Stage 3 of the algorithm was constructed. According to the RIDGE-regression method, the minimum of function (1) was found to determine the model parameters:

$$L = \sum_{i=1}^{n}(y_i - \hat{y}_i)^2 + \lambda \sum_{i=1}^{n} \beta_i^2 \quad (1)$$

where y_i are the experimental values of the regressant, $\hat{y}_i$ are the theoretical values of the regressant, which is calculated based on the constructed regression equation; λ is the set parameter (penalty); β_i are the coefficients of the regression model.

The parameter λ that is applied is a penalty for large parameter values β_i. This parameter allows building a more sustainable solution. To find the parameter λ, cross-validation is performed and the optimal values of the parameter λ are determined.

At Stage 5, the coefficients of regression models are analysed and indicators Δ_i are calculated. These indicators allow finding the degree of influence of factors on the indicator under study and rank the factors in order of their importance for the indicator under study.

To find the share of the influence of weather factors in the total impact of all factors, the coefficient Δ_j was calculated according to the following Equation (2):

$$\Delta_i = \left| \frac{\tilde{a}_i \cdot r_{YX_i}}{R^2} \right| \quad (2)$$

where $\tilde{a}_i$ are the parameters of the regression model in normalised factors $\tilde{X}_i$; r_{YX_i} are the correlation coefficients; R^2 is the determination coefficient.

Coefficients of the corresponding regression model in normalised factors were calculated using Equation (3):

$$\tilde{a}_i = a_i \frac{\bar{S}_{X_i}}{\bar{S}_Y} \quad (3)$$

where a_i are the calculated coefficients of the regression model (2); $\bar{S}_{X_i}$ is the standard deviation of factors X_i; $\bar{S}_Y$ is the standard deviation of the indicator Y under study.

When conducting the analysis of variance, the statistical difference between varieties was determined using ANOVA for each year separately (significance level 0.05).

RESULTS AND DISCUSSION

Sweet cherry fruits are mainly used for fresh consumption, so their mass and size are of the greatest importance among external quality indicators (Voca *et al.,* 2007; Turner *et al.,* 2008) and affects the market value (Ruisa *et al.,* 2008). As a result of 20 years of research, it was proved that in the conditions of the Southern Steppe subzone of Ukraine, the average mass of the sweet cherry fruit is 8.41 g, and the pyrenes – 0.56 g. In the group of early ripening varieties, the average mass of sweet cherries was at the level of 7.61 g, which is 10.51% less compared to the average varietal value (Table 1). The average pyrene mass of early-ripening sweet cherry varieties was 0.64 g, which is 12.5% more compared

to the average varietal value. The minimum fruit mass was set in 2018 for the early-ripening Merchant variety (4.46 g), which is 41.39% less than the average varietal value. The maximum fruit mass (11.56 g) was recorded in 2016 for the Kazka variety, which is 52.03% higher than the average varietal value. In the group of early-ripening varieties, according to the results of 20 years of research, the Kazka variety was characterised by the largest fruit mass, and the smallest – Merchant with LSD_{05} 0.649. Research by M. Schuster et al. (2014) in German conditions found that the average mass of cherry fruits for the early-ripening Narana variety was 9.1 g, and for the Swing variety – 10.9 g. In 2008, the fruits of the Rubinova Rannia variety had the minimum average pyrene mass (0.4 g), which is 37.50% less than the average varietal value. The maximum pyrene mass index was recorded in Sweet Erlise fruits of 0.91 g in 2016, the excess over the average varietal value was 42.18%. The highest pyrene mass in the fruits of early-ripening sweet cherry varieties for all the years of research was found in the Sweet Erlise variety, and the lowest – in Rubinova Rannia with LSD_{05} 0.084.

***Table 1**. Fruit and pyrene mass and their ratio in sweet cherry fruits of early ripening varieties (2008-2019), $\bar{x} \pm s\bar{x}$, n=5*

Cultivar	Fruit mass				Pyrene mass				The ratio of pyrene mass to fruit, %
	average, g	min, g	max, g	Vp, %	average, g	min, g	max, g	Vp, %	
Rubinova Rannia	7.32±0.41	5.05	9.07	19.4	0.49±0.01	0.40	0.57	11.5	6.69
Valerii Chkalov	8.35±0.29	6.46	9.43	12.2	0.72±0.02	0.61	0.85	11.9	8.62
Sweet Erlise	7.73±0.23	6.51	9.03	10.6	0.74±0.02	0.58	0.91	12.4	9.57
Merchant	6.25±0.40	4.46	8.34	22.5	0.61±0.03	0.49	0.81	17.5	9.76
Kazka	9.10±0.36	7.17	11.56	14.0	0.60±0.03	0.46	0.89	19.5	6.59
Bigarro Burlat	6.79±0.29	5.38	8.25	14.9	0.63±0.02	0.49	0.80	13.1	9.27
Zabuta	7.73±0.33	6.38	9.60	15.1	0.70±0.03	0.52	0.87	16.7	9.05
Average value	7.61±0.33	5.91	9.32	15.5	0.64±0.02	0.50	0.81	14.6	8.40
LSD_{05}		0.649				0.084			

The average mass of sweet cherry fruits of medium (8.39 g) and late (9.23 g) ripening periods was 0.23% and 8.88%, respectively, higher than the average varietal value (Tables 2, 3).

***Table 2**. Fruit and pyrene mass and their ratio in sweet cherry fruits of medium-ripening varieties (2008-2019), $\bar{x} \pm s\bar{x}$, n=5*

Cultivar	Fruit mass				Pyrene mass				The ratio of pyrene mass to fruit, %
	Average, g	Min, g	Max, g	Vp, %	Average, g	min, g	max, g	Vp, %	
Vynka	7.46±0.25	6.34	8.89	11.8	0.62±0.02	0.49	0.72	11.4	8.31
Pervistok	8.13±0.37	6.69	10.98	15.9	0.46±0.02	0.39	0.63	19.7	5.65
Temp	8.90±0.27	7.65	10.55	10.8	0.77±0.02	0.60	0.93	12.6	8.65
Liubymytsia Turovtseva	7.47±0.48	5.11	10.09	22.5	0.53±0.01	0.41	0.62	12.2	7.09
Talisman	8.93±0.51	6.80	11.81	19.8	0.69±0.03	0.52	0.89	16.2	7.72
Dilema	9.91±0.43	7.92	12.01	15.0	0.60±0.02	0.46	0.77	17.0	6.05
Melitopol Black	9.37±0.38	7.63	11.81	14.2	0.47±0.01	0.40	0.60	11.5	9.05
Cordia	8.54±0.65	5.51	11.75	26.6	0.64±0.02	0.50	0.74	12.6	5.01
Octavia	8.69±0.45	6.01	10.77	18.2	0.52±0.01	0.40	0.61	11.6	6.08
Orion	6.85±0.40	4.61	8.77	20.7	0.39±0.01	0.31	0.50	15.9	5.69
Chervneva Rannia	7.48±0.27	5.90	8.68	12.8	0.49±0.02	0.36	0.67	18.7	6.55
Dachnytsia	8.09±0.40	5.71	9.98	17.2	0.50±0.01	0.37	0.61	12.3	6.18
Prostir	9.34±0.35	7.78	11.67	13.2	0.67±0.03	0.54	0.91	16.1	7.17
Average value	8.39±0.40	6.43	10.59	16.8	0.56±0.02	0.44	0.70	17.3	6.67
LSD_{05}		0.520				0.046			

According to M. Schuster et al. (2014), the average mass of medium-ripening sweet cherries of the Areko variety was 12.3 g. Late-ripening sweet cherry varieties had the best fruit mass. The average pyrene mass (0.56 g) of medium-ripening varieties was at the level of the average varietal value. In late-ripening sweet cherries, the average pyrene mass was 11.11% higher than the average varietal value. The minimum fruit mass in 2012 and 2008 was characterised by the Orion (4.61 g) and Kolkhoznitsa (5.67 g) varieties, which is 45.05% and 38.57%, respectively, less than the average varietal value. The maximum fruit mass was set for the medium-ripening Dilema variety (12.01 g) in 2010 and the late-ripening Udivitelna variety (14.54 g) in 2011, which exceeds the average varietal value by 43.14% and 57.53%. Among the varieties of the medium and late ripening group, the maximum average fruit mass was found in the fruits of the medium-ripening Dilema variety (9.91 g) and the late-ripening Udivitelna variety (12.18 g). Nine sweet cherry varieties were evaluated based on the external characteristics of fruit quality in the Mediterranean part of Croatia (Radunić *et al.,* 2014). It was found that the fruits of the sweet cherry varieties Isabella and Tugarka had an average mass of more than 7.5 g, and the Burlat variety – less than 5 g. E. Iurea et al. (2019) determined that Elaiaşi (8.9 g) and Croma (9.4 g) varieties had the highest fruit mass in Romania. Research by M. Corneanu et al. (2021) in the conditions of Romania recorded the highest index of cherry fruit mass for the Andreiaş variety (10.0 g).

The minimum pyrene mass was found in the fruits of the medium-ripening Orion variety (0.31 g) in 2008 and the late-ripening Udivitelna variety (0.3 g) in 2017, which is 44.64% and 52.38% less than the average varietal value, respectively. The maximum values of pyrene mass were recorded in the fruits of the medium-ripening Temp variety (0.93 g) in 2011 and the late-ripening Kosmichna variety (0.91 g) in 2015, which exceeds the average varietal value by 67.85% and 44.44%, respectively. According to research by K.M. Bhat et al. (2018) in India, the highest pyrene mass was observed in sweet cherry fruits of the Regina and Misri varieties at the level of 0.48 g, and the lowest – 0.34 g – in the Stella variety.

Table 3. *Fruit and pyrene mass and their ratio in late ripening sweet cherry fruits (2008-2019),* $\bar{x} \pm s_{\bar{x}}$ *, n=5*

Cultivar	Fruit mass				Pyrene mass				The ratio of fruit mass to pyrene, %
	Average, g	min, g	max, g	Vp, %	Average, g	min, g	max, g	Vp, %	
Krupnoplidna	11.67±0.47	8.73	13.72	14.0	0.51±0.02	0.40	0.61	14.2	4.37
Karina	9.57±0.37	7.55	11.94	13.5	0.66±0.02	0.56	0.79	11.1	6.89
Regina	7.99±0.23	6.71	9.00	10.1	0.74±0.02	0.62	0.88	10.4	9.26
Mirazh	7.73±0.24	6.30	8.81	11.1	0.58±0.01	0.46	0.67	11.5	7.50
Udivitelna	12.18±0.51	10.01	14.60	14.7	0.43±0.02	0.30	0.56	20.9	3.53
Zodiak	8.95±0.29	7.23	10.05	11.2	0.56±0.01	0.47	0.64	11.3	6.25
Surprise	7.37±0.28	6.00	9.40	13.2	0.57±0.03	0.40	0.79	21.2	7.73
Kolkhoznytsia	8.14±0.37	5.67	9.93	16.0	0.70±0.04	0.40	0.88	21.3	8.59
Kosmichna	9.91±0.41	8.05	12.21	14.6	0.76±0.02	0.56	0.91	13.4	9.44
Prazdnychna	7.27±0.27	5.71	8.76	13.2	0.71±0.02	0.52	0.82	13.5	5.16
Anons	9.84±0.37	7.96	11.77	13.2	0.60±0.02	0.50	0.69	12.4	6.09
Temporion	9.68±0.43	7.44	12.01	15.4	0.75±0.02	0.68	0.89	11.1	7.74
Meotida	9.78±0.39	7.21	11.72	14.1	0.66±0.02	0.46	0.79	14.9	6.74
Average value	9.23±0.35	7.27	11.07	13.4	0.63±0.03	0.48	0.76	14.4	6.82
LSD_{05}		0.538				0.039			

Consumers value cherry fruits with a smaller pyrene mass and a smaller percentage of pyrenes in the total mass of the fruit (Maglakelidze *et al.,* 2017). In the fruits of the early-ripening sweet cherry Kazka variety, the best ratio of pyrene to pulp was determined at the level of 6.59% (Table 1). The best ratio of pyrene to sweet cherry fruit pulp was determined in late-ripening varieties Udivitelna (3.53%), Krupnoplidna (4.37%) and Prazdnichna (5.16%), and medium-ripening varieties – Cordia (5.01%), Pervistok (5.65%) and Orion (5.69%). Research by E. Maglakelidze et al. (2017) found that the relative mass of pyrenes to the mass of fresh fruit ranged from 3.7% to 8.4%. According to K.M. Bhat et al. (2018), the highest percentage of pyrenes in the total mass of sweet cherry fruits was recorded at 7.58% in the Makhmali variety.

The results obtained in this study are consistent with the data of other studies on the formation of the average mass of the fruit and pyrene in various

pomological varieties of sweet cherries. Thus, the mass of fruits of sweet cherries ranged from 5.9 g (Scorospelka) to 9.2 g (Andreiaş) in north-eastern Romania (Corneanu *et al.,* 2020). As a result of investigating nine foreign varieties in the conditions of Georgia, it was found that all the varieties under study had large fruits except Moro (Maglakelidze *et al.,* 2017). The average sweet cherry fruit mass ranged from 6.9 g (Moro) to 10.2 g (Celeste), and the pyrene mass ranged from 0.2 g (Burlat) to 0.56 g (Celeste). Research by A. Bieniek et al. (2011) found that in Lithuanian conditions, the average mass of sweet cherry fruits ranged from 3.78 to 6.45 g over three years.

Given the dessert and technological qualities of fruits, varieties with best fruit and pyrene mass indicators, but also their stability over the years, are of particular value. To assess the stability of the varieties of different ripening periods under study in relation to the weather conditions of the growing years, the variation coefficient was used (Vp). It is known that the sample variability is considered low or not substantial at Vp 10%, average – Vp=10-20=%, strong or substantial – 20% of the indicator under study (Ivanova *et al.,* 2020). In the group of varieties of early ripening, the average variability of fruit and pyrene mass over the years of research was established (Table 1). The most substantial influence of weather conditions on the formation of fruit mass was observed in the Merchant variety (Vp=22.5%) and in the Kazka variety (Vp=19.5%). Sweet Erlise (Vp=10.6%), and Rubinova Rannia (Vp=11.5%) were the most consistent in the group of early ripening varieties in terms of fruit mass. The variability of the indicators in sweet cherry fruits of medium- and late-ripening varieties over the years of research was average and substantial (Tables 2, 3). In the group of varieties of medium ripening period, the Temp variety (Vp=10.8%) was identified as the most stable in terms of fruit mass, and Vynka (Vp=11.4%) was identified as the most stable in terms of pyrene mass (Table 2). The most variable variety in terms of sweet cherry fruit mass was Cordia (Vp=26.6%), and Pervistok (Vp=19.7%).

***Table 4**. Results of two-factor analysis of variance*

Variation source	Fruit mass				Pyrene mass			
	variance	F_{fact}	$F_{tab\ 095}$	impact, %	variance	F_{fact}	$F_{tab\ 095}$	impact, %
group of early ripening sweet cherry varieties								
Factor A (year)	19.61	123.2	1.8	39.7	0.09	34.8	1.8	24.4
Factor B (variety)	32.35	203.3	2.2	35.7	0.26	98.1	2.2	37.5
AB interaction	1.61	10.1	1.4	19.6	0.01	6.4	1.4	27.0
group of medium ripening sweet cherry varieties								
Factor A (year)	61.08	598.7	1.8	51.5	0.12	153.2	1.8	16.5
Factor B (variety)	29.71	291.2	1.8	27.3	0.42	513.2	1.8	60.5
AB interaction	1.795	17.5	1.3	18.1	0.01	15.0	1.3	19.5
group of late ripening sweet cherry varieties								
Factor A (year)	42.16	384.7	1.8	26.1	0.16	275.1	1.8	21.5
Factor B (variety)	85.37	778.9	1.8	57.8	0.37	626.3	1.8	53.4
AB interaction	1.88	17.2	1.3	14.0	0.01	24.1	1.3	22.6

In the group of late ripening varieties (Table 3), the highest variability in fruit and pyrene mass was recorded in the Kolkhoznytsia (Vp=16.0%) and Udivitelna (Vp=20.9 %) varieties, respectively, and the lowest – in the Regina variety (Vp=10.1% and 10.4%). The dominant influence on the formation of sweet cherry fruit mass was exerted by the weather conditions of the research years (Factor A) with the share of influence for early-ripening varieties – 39.7%, medium-ripening varieties – 51.5%, and late-ripening varieties – 26.1% (Table 4).

The share of influence of varietal characteristics (Factor B) was less significant for the sweet cherry varieties of early (35.7%) and medium (27.3%) ripening periods. For late-ripening sweet cherry varieties, it was 57.8%. Varietal characteristics (Factor B) had a dominant influence on the formation of pyrene mass in sweet cherry fruits, with a share of influence for early-ripening varieties – 37.5%, medium-ripening varieties – 60.5%, and late-ripening varieties – 53.4%. The influence of weather conditions in the research years (Factor A) was less significant. Proportion of the influence of Factor A on the formation of pyrene mass in sweet cherry fruits was 24.4% for early-ripening varieties, 16.5% for medium-ripening varieties, and 21.5% for late-ripening varieties.

According to the proposed research algorithm, the hypothesis H_0 was tested regarding the significance of correlation coefficients by Student's t-test at the significance level α=0.05. Significant paired correlation coefficients corresponded to the condition $|r_{YX_i}| > 0.55$,

i=1..*n*, *n* is the number of factors under study. Therefore, those weather factors that have the value of paired correlation coefficients from the specified interval were selected. Table 5 presents the symbols for factors.

Table 5. *Conditional factor designations*

Factor (X_i,)	Conditional factor designations, (X_i,)
X_1	Average monthly precipitation in May, mm
X_2	Average monthly precipitation in June, mm
X_3	Average monthly relative humidity in May, %
X_4	Average monthly relative humidity in June, %
X_5	Average minimum relative humidity in May, %
X_6	Average minimum relative humidity in June, %
X_7	Hydrothermal coefficient
X_8	Number of days with precipitation exceeding 1 mm in May, day
X_9	Difference between average maximum and minimum temperatures in May, °C
X_{10}	Amount of precipitation during the flowering period, mm
X_{11}	Amount of precipitation during fruit ripening, mm
X_{12}	Total number of days with precipitation during the flowering period, mm

For further analysis, a matrix of paired correlation coefficients was constructed, which is presented in Table 6. Notably, he values of the correlation coefficients between the factors themselves are close to ±1, which indicates a close correlation between them (Table 6).

Table 6. *Correlation matrix, factor analysis*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}
x_1	1.00											
x_2	0.22	1.00										
x_3	0.73	0.08	1.00									
x_4	0.24	0.57	0.29	1.00								
x_5	0.78	0.05	0.97	0.29	1.00							
x_6	0.38	0.52	0.43	0.92	0.44	1.00						
x_7	0.27	0.52	0.48	0.21	0.32	0.32	1.00					
x_8	0.76	0.30	0.80	0.42	0.82	0.55	0.28	1.00				
x_9	-0.60	0.14	-0.85	-0.35	-0.92	-0.53	-0.13	-0.72	1.00			
x_{10}	0.58	0.59	0.62	0.77	0.56	0.78	0.57	0.64	-0.44	1.00		
x_{11}	0.41	0.75	0.28	0.54	0.23	0.42	0.56	0.40	-0.03	0.63	1.00	
x_{12}	0.26	0.52	0.53	0.83	0.50	0.81	0.33	0.69	-0.51	0.71	0.53	1.00

Substantially correlated factors: X_1 and X_3, X_1 and X_5; X_2 and X_{11}; X_3 and X_5, X_3 and X_8, X_3 and X_9; X_4 and X_6, X_4 and X_{10}, X_4 and X_{12}; X_5 and X_8, X_5 and X_9; X_6 and X_{10}; X_{11} and X_{12}. That is, the multicoleniarity effect is manifested.

As indicated in point 4 of the general algorithm, a regression model in multicollinearity conditions was constructed using the Ridge-regression method. The Ridge-regression method regularises parameters and allows building a regression model, the coefficients of which are unbiased estimates of the parameters of the corresponding generalised model.

As a result of cross-validation, a parameter λ=29.76351 was found for the regression model of the dependence of the indicator Y_1 – sweet cherry fruit mass for early ripening varieties on weather factors. For the regression model of the dependence of the indicator Y_2 – sweet cherry fruit mass for medium-ripening varieties on weather factors, parameter λ=3,792.6901 was found.

For the regression model of the dependence of the indicator Y_3 – sweet cherry fruit mass for late-ripening varieties on weather factors, parameter λ=1,438.4498 was found.

The regression model of type (1) of the dependence of the indicator Y_1 – fruit mass on weather factors (in normalised factors) for early-ripening varieties has the following type (4):

$$\hat{Y}_1 = 0.02455X_1 - 0.02735X_3 + 0.6597X_5 + 0.7736X_8 - 0.5087X_9 + 0.6691X_{10} + 0.7213X_{12} \quad (4)$$

where $\hat{Y}_1$ is the forecast value of the fruit mass indicator for early-ripening varieties of sweet cherries.

Coefficient of determination calculated based on the constructed model R^2=0.8807, which indicates a substantial influence of factors on the indicator under study with random errors.

The regression model of type (1) of the dependence of the indicator Y_2 – fruit mass on weather factors (in normalised factors) for medium-ripening varieties has the following type (5):

$$\hat{Y}_2 = 0.00141X_2 - 0.0000698X_4 - 8.4341 \cdot 10^{-5} X_6 + 1.3633 \cdot 10^{-4} X_7 + \\ +1.9166 \cdot 10^{-3}X_{10} + 8.7028 \cdot 10^{-3}X_{11} + 2.2799 \cdot 10^{-3}X_{12} \quad (5)$$

where $\hat{Y}_2$ is the forecast value of the fruit mass indicator for medium-ripening varieties of sweet cherries.

Coefficient of determination calculated based on the constructed model R^2=0.8731, which indicates a substantial influence of factors on the indicator under study with random errors.

The regression model of type (1) of the dependence of the indicator Y_3 – fruit mass on weather factors (in normalised factors) for late-ripening varieties has the following type (6):

$$\hat{Y}_3 = 0.00192X_2 - 1.7666 \cdot 10^{-3}X_4 - 5.1931 \cdot 10^{-3} X_6 + 6.3535 \cdot 10^{-3}X_{10} + \\ +2.5183 \cdot 10^{-5}X_{11} + 4.7780 \cdot 10^{-3}X_{12} \quad (6)$$

where $\hat{Y}_3$ is the forecast value of the fruit mass indicator for late-ripening varieties of sweet cherries.

Coefficient of determination calculated based on the constructed model R^2=0.7506, which indicates a substantial influence of factors on the indicator under study with random errors.

The regression model of type (1) of the dependence of the indicator Z_1 – pyrene mass on weather factors (in normalised factors) for early-ripening varieties has the following type (7):

$$\hat{Z}_1 = 9.8473 \cdot 10^{-4}X_1 + 2.7925 \cdot 10^{-4}X_4 + 1.4253 \cdot 10^{-5}X_6 + 5.63382 \cdot 10^{-5}X_{14} + 5.4247 \cdot 10^{-5}X_{20} \quad (7)$$

where $\hat{Z}_1$ is the forecast value of the fruit mass indicator for early-ripening varieties of sweet cherries.

Coefficient of determination calculated based on the constructed model R^2=0.9203, which indicates a substantial influence of factors on the indicator under study with random errors.

The regression model of type (1) of the dependence of the indicator Z_2 – pyrene mass on weather factors (in normalised factors) for medium-ripening varieties has the following type (8):

$$\hat{Z}_2 = 3.7073 \cdot 10^{-4}X_1 + 1.2553 \cdot 10^{-3}X_2 - 1.2780 \cdot 10^{-5}X_3 + 1.2107 \cdot 10^{-4}X_4 + \\ +2.5821 \cdot 10^{-5}X_5 + 2.0657 \cdot 10^{-5}X_6 + 1.4705 \cdot 10^{-4}X_7 - 6.6863 \cdot 10^{-8}X_{17} + 1.5693 \cdot 10^{-4}X_9 \quad (8)$$

where $\hat{Z}_2$ is the forecast value of the pyrene mass indicator for medium-ripening sweet cherry varieties.

Coefficient of determination calculated based on the constructed model R^2=0.9013, which indicates a substantial influence of factors on the indicator under study with random errors.

The regression model of type (1) of the dependence of the indicator Z_3 – pyrene mass on weather factors (in normalised factors) for late-ripening varieties has the following type (9):

$$\hat{Z}_3 = 0.00038X_1 + 0.00128X_2 + 0.003198X_3 - 0.0024X_4 + 0.0032X_5 - 0.00047X_6 + \\ +0.0085X_7 - 0.0059_X - 0.00029X_9 \quad (9)$$

where $\hat{Z}_3$ is the forecast value of the pyrene mass indicator for late-ripening sweet cherry varieties.

Coefficient of determination calculated based on the constructed model R^2=0.9261, which indicates a substantial influence of factors on the indicator under study with random errors. Based on the constructed models according to formula (2), indicators Δ_i (i=1..12) were calculated, which characterise the degree of influence of factors on the formation of the mass of fruits of the culture under study. Factors in sweet cherry varieties of early, medium, and late ripening periods were ranked to their degree of importance. For sweet cherry varieties of early, medium, and late ripening periods, these are the following factors: $X_1, X_3, X_5, X_8, X_9, X_{10}, X_{12}$; $X_2, X_4, X_6, X_7, X_{10}, X_{11}, X_{12}$; $X_2, X_4, X_6, X_{10}, X_{11}, X_{12}$, respectively. Table 7 presents the calculated indicators and ranks of factors.

***Table 7**. Table of pairwise correlation coefficients ($r_{Y_jX_i}$), indicators of the share of influence (Δ_i) and ranks of weather factors (X_i) on the formation of fruit mass in sweet cherry varieties of early, medium, and late ripening periods*

Factor (X_i)	Conventional notation of the factor (X_i)	Paired correlation coefficients ($r_{Y_jX_i}$), coefficients of the share of influence of factors (Δ_i) and indicators of factor ranks for varieties of different ripeness groups								
		Early			Average			Late		
		$r_{y_1x_i}$	Δ_i,%	Rank	$r_{y_1x_i}$	Δ_i,%	Rank	$r_{y_1x_i}$	Δ_i,%	Rank
X_1	Average monthly precipitation in May, mm	0.725	12.20	2	*	–	–	*	–	–
X_2	Average monthly precipitation in June, mm	*	–	–	0.905	55.03	1	0.843	58.29	1
X_3	Average monthly relative humidity in May, %	0.619	11.60	3	*	–	–	*	–	–
X_4	Average monthly relative humidity in June, %	*	–	–	0.496	1.49	5	0.617	3.92	5
X_5	Average minimum relative humidity in May, %	0.659	2.53	6	*	–	–	*	–	–
X_6	Average minimum relative humidity in June, %	*	–	–	0.449	0.16	7	0.662	12.38	3
X_7	Hydrothermal coefficient	*	–	–	0.597	0.35	6	*	–	–
X_8	Number of days with precipitation exceeding 1 mm in May, day	0.773	14.70	1	*	–	–	*	–	–
X_9	Difference between average maximum and minimum temperatures in May, °C	0.508	7.21	4	*	–	–	*	–	–
X_{10}	Amount of precipitation during the flowering period, mm	0.669	2.38	7	0.613	5.05	4	0.648	14.83	2
X_{11}	Amount of precipitation during fruit ripening, mm	*	–	–	0.857	32.07	2	0.622	0.05	6
X_{12}	Total number of days with precipitation during the flowering period, mm	0.721	4.93	5	0.595	5.83	3	0.611	10.51	4

***Note**: *against the background of high and medium values of correlation coefficients, high values of the factor's participation in fruit mass formation were not obtained; **indicators taken for research on the recommendation of professional experts with small and medium correlation values, but based on mathematical calculations of the shares of factors involved in the formation of the fruit mass index, received high values Δ_i,%*

The resulting models also allowed calculating the indicators Δ_i (i=1..9), which characterise the degree of influence of factors on the formation of the pyrene mass of the culture under study (Table 8). The ranking of factors in the sweet cherry varieties of all ripening periods to their degree of significance. For early-, medium-, and late-ripening sweet cherry varieties, the calculated indicators and ranks of factors were given as follows: X_1, X_4, X_6, X_7, X_9; $X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9$; $X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9$ – respectively. Table 8 presents the calculated indicators and ranks of factors.

In varieties of sweet cherry of three ripening periods under study, the share of influence of weather factors Δ_i on the formation of fruit mass varied within 0.05-58.29%. The share of influence of the factors under study on the formation of pyrene mass in sweet cherry varieties was in the range of 0.00-73.63% (Table 7). According to Table 7, the first rank and maximum effect on the formation of fruit mass in early-ripening varieties was obtained by the X_8 Factor – the number of days with precipitation exceeding 1 mm in May (Δ_{X8}-14.70%). For varieties of medium and late ripening periods the average monthly amount of precipitation in June received Rank 1 (Δ_{X2} – 55.03 and 58.29% – respectively) and according to the results of statistical calculations, it maximally affected the formation of fruit mass in the context of the groups under study.

Table 8. *Table of pairwise correlation coefficients* ($r_{Y_jX_i}$), *indicators of the share of influence* (Δ_i) *and ranks of weather factors* (X_i) *on the formation of pyrene mass in early-, medium-, and late-ripening sweet cherry varieties*

Factor (X_i)	Conditional factor designation (X_i)	Paired correlation coefficients ($r_{Y_jX_i}$), coefficients of the share of influence of factors (Δ_i) and indicators of factor ranks for varieties of different ripeness groups								
		Early			Average			Late		
		$r_{y_1x_i}$	Δ_i,%	Rank	$r_{y_1x_i}$	Δ_i,%	Rank	$r_{y_1x_i}$	Δ_i,%	Rank
X_1	Average monthly precipitation in May, mm	0.833	56.37	1	0.475**	11.32	2	0.480**	1.27	8
X_2	Average monthly precipitation in June, mm	*	–	–	0.912	73.63	1	0.829	7.42	5
X_3	Average maximum air temperature in June, °C	*	–	–	0.344**	0.22	8	0.361**	8.04	4
X_4	Average monthly relative humidity in May, %	0.808	15.51	3	0.344**	2.68	5	0.291**	5.00	6
X_5	Average monthly relative humidity in June, %	*	–	–	0.530	0.88	6	0.656	14.69	3
X_6	Hydrothermal coefficient	0.482	0.49	5	0.603	0.80	7	0.349**	1.18	9
X_7	Number of days with precipitation exceeding 1 mm in May, day	0.682	2.64	4	0.573	5.42	4	0.631	37.47	1
X_8	Difference between average maximum and minimum temperatures in June, °C	*	–	–	0.346**	0.00	9	0.567	23.60	2
X_9	Amount of precipitation during the flowering period, mm	0.670	24.99	2	0.667	6.73	3	0.651	1.33	7

Note: **against the background of high and medium values of correlation coefficients, high values of the factor's participation in pyrene mass formation were not obtained; **indicators taken for research on the recommendation of professional experts with small and medium correlation values, but based on mathematical calculations of the shares of factors involved in the formation of the pyrene mass index, received high values,* Δ_i,%

The data in Table 8 suggest that for the indicator of pyrene mass in sweet cherry fruits for early-ripening varieties, the decisive factor and Rank 1 was obtained by average monthly precipitation in May (Δ_{X1} – 56.37%). The analysis results of the influence of weather factors on the formation of pyrene mass indicate that for medium-ripening varieties, the decisive factor was the average monthly precipitation in June Δ_{X2} – 73.63%, for late-ripening – the number of days with precipitation exceeding 1 mm in May (Δ_{X7} – 37.47). The above suggests that the formation of fruit mass and pyrene in early-ripening, medium-ripening, and late-ripening sweet cherry varieties is most influenced by the humidity indicators of the last period of fruit ripening in May and June.

CONCLUSIONS

1. In the conditions of the Southern Steppe zone of Ukraine, the average mass of the fruit was 8.41 g, and the average mass of the pyrene was 0.56 g. The study established that the optimal fruit mass was found in late-ripening sweet cherry varieties (7.27-12.18 g), which on average exceeds the average varietal value by 8.88%.

2. The maximum average mass of the fruit was found in the early-ripening Kazka variety (9.10 g), medium-ripening Dilema (9.91 g) and late-ripening Udivitelna (12.18 g). In the fruits of early-, medium-, and late-ripening sweet cherry varieties, over all the years of research, Sweet Erlise, Temp, and Kosmichna varieties were characterised by the highest pyrene mass, and Rubinova Rannia, Pervistok, Melitopol Black and Krupnoplidna varieties were characterised by the smallest pyrene mass.

3. Among the varieties of sweet cherries under study, the following were distinguished according to the best ratio of pyrene to fruit pulp: late-ripening – Udivitelna, Krupnoplidna, and Prazdnichna (3.53-5.16%); medium-ripening - Cordia, Pervistok, and Orion (5.01-5.69%); early-ripening – Kazka (6.59%).

4. Sweet Erlise (Vp=10.6%), mid-ripening – Temp (Vp=10.8%) and late-ripening – Regina variety (Vp=10.1%) were identified as the most consistent sweet cherry fruits by mass. The lowest variability in the content of pyrene mass in sweet cherry fruits was recorded in the early-ripening variety Rubinova Rannia (Vp=11.5 %), medium-ripening – Vynka (Vp=11.4%) and late-ripening – Regina (Vp=10.4 %).

5. Weather conditions of the years of research had a dominant influence on the formation of sweet cherry fruit mass of different ripening periods (Vp=26.1-51.5%), and pyrene mass was influenced by varietal characteristics (Vp=37.5-60.5%).

6. The number of days with precipitation exceeding 1 mm in May had the maximum influence on the formation of the fruit mass of early-ripening varieties, and for medium- and late-ripening varieties – the average monthly amount of precipitation in June. The average monthly amount of precipitation in May was crucial for the formation of pyrene mass in sweet cherry fruits for early ripening varieties,, for medium-ripening varieties – the average monthly amount of precipitation in June, for late-ripening varieties – the number of days with precipitation exceeding 1 mm in May.

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Оцінка впливу погодних факторів на кількісні показники плодів черешні методом Ridge-регресії

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Анотація. Черешня є улюбленою кісточковою культурою у споживачів плодової продукції. Наразі попит на черешню зростає, що спонукає розширити сортовий асортимент культури з різними строками достигання. Метою досліджень було розробити математичну модель для прогнозу формування маси плоду і кісточки черешні залежно від погодних факторів і сортових особливостей. Дослідження проводили протягом 2008–2019 рр. в умовах Південної Степової зони України на 33 сортах черешні раннього, середнього і пізнього строків достигання. Середня маса плоду черешні за роки досліджень становить 8,41 г, а середня маса кісточки – 0,56 г. Сорти черешні пізнього строку достигання мали оптимальну масу плодів (7,27–12,18 г). За максимальною середньою масою плоду виділено сорти Казка, Ділема і Космічна. Найменшу масу кісточки у плодах черешні мали сорти Рубінова рання, Первисток, Мелітопольска чорна і Крупноплідна. У групі раннього строку достигання оптимальне співвідношення кісточки до м'якоті плодів визначено у сорту Казка, у середньостиглих – Кордія, Первісток і Оріон, у пізньостиглих – Удівітєльна, Крупноплідна і Празднічна. Найменшу варіативність за масою плодів черешні у групі ранньостиглих сортів виділено Sweet Erlise, середньостиглих – Темп і пізньостиглих – Регіна, а за масою кісточки – Рубінова Рання, Винка і Регіна відповідно. На формування маси плоду домінуючий вплив для усіх досліджуваних сортів черешні мали погодні умови, а маси кісточки – сортові особливості. Максимальний вплив на формування маси плоду черешні ранніх сортів забезпечив показник – кількість днів з опадами у травні більше 1 мм, а середньо- і пізньостиглих сортів – середньомісячна сума опадів в червні. Вирішальне значення на формування маси кісточки у плодах черешні сортів раннього строку достигання має середньомісячна сума опадів у травні, середнього строку достигання – середньомісячна сума опадів в червні, пізнього строку достигання – кількість днів з опадами в травні більше 1 мм

Ключові слова: маса кісточки, маса плоду, співвідношення кісточки до м'якоті плоду, варіація показників, кліматичні умови, регресійна модель

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Analysis of Rural Areas of Ukraine on the Basis of ESA WorldCover 2020

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Abstract. At present, GIS technologies penetrate various spheres of socio-economic life of humankind. In this paper, based on GIS technologies, the main classes of the land cover of Ukraine were analysed with further in-depth study in terms of regions and rural and urban areas. The results of this study are based on ESA WorldCover data; according to them, 32% of Ukraine's territory can be attributed to urban areas, while 68% – to rural areas. In general, the analysis showed that Ukraine is characterised by a high degree of land using, so the land that was cultivated in 2020 accounted for 55.5% of its area. 70% of rural areas comprise cultivated areas, 30% – in urban areas. The leaders among the oblasts with the largest share of cultivated lands are Zaporizhzhia (76%), Kirovohrad (76%), Mykolaiv (77%). An inherent feature of Ukraine's land structure is a considerable share of land (15.3%) under meadows, hayfields, and pastures, which are vital in restoration and preservation and as an essential element of regional ecosystems. 66% of the territories of this class are concentrated in rural areas, on urban areas – 34%. Most of them are in Luhansk (26%), Lviv (24%) and Volyn (22%) oblasts. The level of forest cover in Ukraine is 23.3%, with 17.7% being forests and the other 6% – protective forest belts, orchards, and arboretums. Rural areas account for 64% of forested areas. The most forested areas are Zakarpattia (68%), Ivano-Frankivsk (54%) and Zhytomyr (45%), while the least forested are Kherson (4%), Zaporizhzhia (5%) and Mykolaiv (6%). In general, 71% of forested areas are rural and 29% are urban. In Ukraine, the share of surface waters covering the geographical area is 2.4%, of which 71% is in rural territories and 29% – in urban territories. Cherkasy (5%), Zaporizhzhia (6%), and Kherson (8%) oblasts are the top three oblasts in terms of surface water supply with 64%, 63% and 82% in rural areas, respectively (Fig. 8). In turn, the oblasts with the smallest share of open water areas are Zhytomyr (0.5%), Luhansk (0.4%) and Zakarpattia (0.3%) oblasts, with 77%, 33%, and 46%, respectively

Keywords: rural territories, GIS technologies, land cover, cultivated land, forested area

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INTRODUCTION

At the turn of the 21st century, the era of exclusively military space is over, and today a significant part of spacecraft is working for the benefit of socio-economic development of society. Information from spacecraft is particularly useful to support environmental, social, and economic issues. Satellite information, as a source of data for geographic information technologies, allows overcoming the problem of subjectivity or the so-called "anthropogenic factor". The "anthropogenic factor" is manifested in the limited ability of people to visit and describe all parts of the Earth's surface and describe them qualitatively. In addition, regarding the pace of development of statistical analysis methods, the analytical product improves every year as a result of processing information from spacecraft and processed using geographic information systems and technologies. Such a product includes classified images of the Earth's surface.

The availability of reliable initial data on the current state of landscapes, features and trends of their changes depending on social conditions is a necessary condition for economical and balanced nature management. To justify effective conservation measures, it is important to know the dynamics and pace of changes that have occurred in the use of landscapes and what they have caused, how profoundly modern landscapes have changed compared to their natural state and why, what are the regional features of landscape use. The basis for solving these problems is the analysis of spatial differences in land use at the level of rural and urban areas.

The consequences of intensive land use, which has recently become a global problem, are manifested in deforestation, increasing arable land, ploughing, depletion of water and land resources to provide the world's growing population with natural resources, energy, and food. Irrational use of nature causes disruption of ecosystems, leads to considerable loss of biodiversity, and disrupts the resilience of geosystems, their ability to self-regulate. In addition, changes in land use cause an impact on regional climatic conditions due to changes in water and energy balances, disruption of the hydrological cycle. In addition to pollution of natural components, there are also habitats of species.

Modern types of land use dictate the needs of developing scientific bases, methods of territorial organisation of land tenure, strengthening the protection of land resources and soil cover, in view of entrepreneurial potential of rural or urban areas. Analysis and assessment of anthropogenic transformation of geosystems is an integral part of the measures of systemic rational land management and sound environmental policy. Deterioration of natural ecosystems is associated with increasing anthropisation of the environment and the natural environment.

The purpose of this study was to geographically separate the rural areas of Ukraine and further analyse their land cover. To achieve this purpose, it was necessary to perform the following tasks: 1) to analyse modern methodological approaches to the classification of land cover; 2) to analyse the land cover of Ukraine (forested areas, cultivated lands, pastures and hayfields, surface waters) with the separation of rural areas; 3) to analyse the land cover at the level of regions of Ukraine with the separation of rural areas.

LITERATURE REVIEW

One of the manifestations of human activity is significant changes in land cover (increase in built-up areas, areas under agriculture, decrease in forest area, etc.). These changes have become one of today's global challenges, as these changes are in most cases unplanned and manifest themselves in the form of ecosystem degradation, drinking water shortages, etc., and in turn have a negative impact on food security around the world. Many scientists from different countries of the world were engaged in the scientific analysis of changes in the earth's cover. Information on the state and change of the Earth's cover is currently in demand in many areas of human activity, especially in rural/urban and regional planning (Hashem & Balakrishnan, 2015; Liou *et al.,* 2017; Lyzhnyk & Svidzinskaya, 2014), monitoring the condition of the environment and assessing the anthropogenic impact on it (Mutanga *et al.,* 2014; Nguyen *et al.,* 2016; Nguyen & Liou, 2019b), forecasting and monitoring the consequences of disasters caused by natural and anthropogenic factors (Maxwell *et al.,* 2018; Talukdar *et al.,* 2020), satellite crop monitoring and assessment of the soil condition and its type (Braun & Hochschild, 2017; Chen *et al.,* 2019; Lyzhnyk & Svidzinskaya, 2014), etc. The reasons for the widespread implementation of land monitoring in various spheres of human activity are primarily due to the development of remote sensing hardware in the form of such spacecraft as Landsat, SPOT, Sentinel, IRS, ASTER, MODIS. In addition, a powerful stimulus for the development of this area is the implementation of statistical methods in classification of the Earth's surface in the form of machine learning algorithms (Maxwell *et al.,* 2018; Mutanga *et al.,* 2014). Methods of machine learning are divided into two branches: controlled (with a teacher) and uncontrolled (without a teacher) (Halder *et al.,* 2011; Talukdar *et al.,* 2020). Methods of controlled classification include machine learning based on reference vectors (SVM) (Wu *et al.,* 2019), random forest (RF) (Xu *et al.,* 2019), spectral angle mapping (SAM), fuzzy adaptive mapping with resonance theory (Fuzzy ARTMAP), Mahalanobis distance (MD), radial basis function RBF), decision tree (DT), multilayer perception (MLP), naive Bayesian classifier (MLC) and fuzzy logic, while unsupervised classification methods include cluster affinity

propagation algorithm (AP), fuzzy C-means algorithms, K-means algorithm , ISODATA (iterative self-organising data), etc (Chen *et al.,* 2019; Halder *et al.,* 2011).

The use of the above methodological apparatus in the study and analysis of the earth's land cover was carried out by scientific teams from many scientific centres around the world, the main achievements of which will be presented in the future. M. Z. Hoque et al. (2022) assessed the dynamics of LULC change and associated ecosystem service values (ESVs) of coastal Bangladesh during 1999-2019 by analysing historical Landsat LULC images and economic valuation techniques, respectively. Findings revealed a high prevalence of rural settlement-based Tree Outside Forest (TOF) land sprawl over agricultural land. As a result, the analysis revealed an increase in built-up, forest, water bodies, and saltpan/aquaculture areas and a decrease in agricultural and bare land areas. A suite of annual land cover and land cover change products has been released by a team of American scientists for the United States. An independently collected land cover reference sample dataset was produced by analysts interpreting Landsat data, high-resolution aerial photographs, and other ancillary data to assess the accuracy of these products (Stehman *et al.,* 2021). Such studies have enabled other teams to improve the accuracy of national classification models and, in general, to have more confidence in satellite imagery. An important study in the development of GIS technologies in the direction of predicting future changes in the earth's cover was done by a team of Brazilian scientists who analysed the future changes in land use and land cover of the advancement of agriculture in the native vegetation areas of the Cerrado/Atlantic forest ecotone in the Prata River basin in 2033, 2050, 2080, and 2100. The modelled future scenarios of LULC indicated the advancement of crop agriculture and decreases in wetlands (banhado), savannahs, riparian forests, seasonal semideciduous forests and wet grasslands (da Cunha *et al.,* 2021).

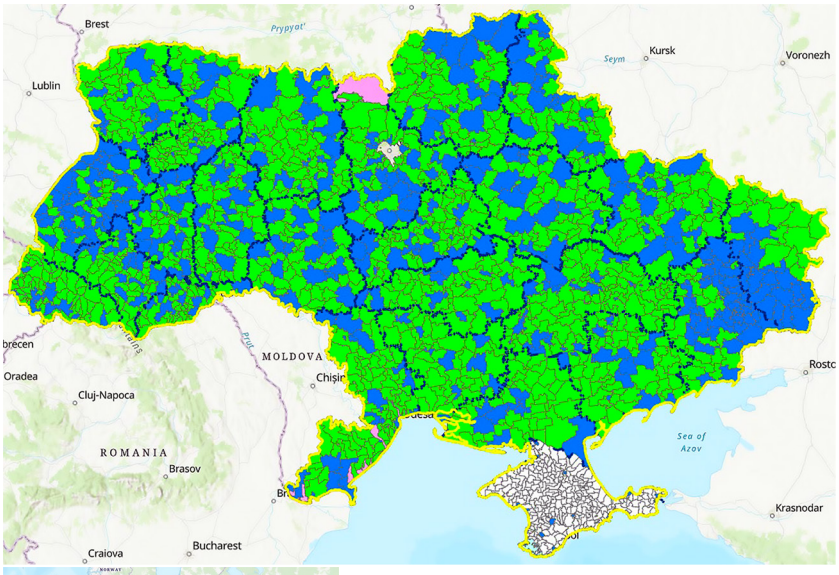
C.M. Viana et al. (2019) intended to apply a long-term LULC analysis in a rural region based on a Landsat time series of 21 years (1995 to 2015). The team selected training samples from the open LULC source data and applied the K-means clustering technique to refine the range of spectral signatures for each LULC class. The results revealed that the proposed method was efficient in classifying a long-term satellite time-series with the accuracy of 76%, providing insights into the main LULC changes that occurred over the years under investigation. The verification of the classification of the earth's cover showed the low accuracy. Therefore, Chinese scientists S. Xu et al. (2019) tried to increase it by combining two models based on images with high spatial resolution. As a result, the combination of SVM and RF classifiers using the C5.0 algorithm is a quick and effective way to improve rural cover classification (Talukdar & Pal, 2018; Talukdar *et al.,* 2020).

MATERIALS AND METHODS

Research area. Ukraine is an independent, democratic country located in Eastern Europe, in the southwestern part of the Eastern European Plain. The area of Ukraine is 603,548 km^2. As of January 1, 2021, the population was 41,588,354 people, according to the State Statistics Service. The largest country in terms of area, the territory of which lies entirely in Europe. The territory of Ukraine lies between 44" and 52" N and 22" and 40" E. The distance between the extreme northern and southern points is 893 km, and between the extreme western and eastern – 1,316 km. Ukraine is a unitary state, which includes 27 regions: 24 oblasts, 1 autonomous republic (AR Crimea) and 2 cities with special status: Kyiv and Sevastopol. These territorial units differ on three grounds: 1) by geographical features they are divided into regions (Crimea, oblasts, districts, cities-regions Kyiv and Sevastopol) and settlements (cities, towns, villages); 2) by their status – on: administrative-territorial units (oblasts, districts), self-governing territorial units – territorial communities (urban, settlement, rural); 3) by place in the system of administrative-territorial organisation of Ukraine – to territorial units of primary level (urban, settlement and rural territorial communities), middle level (districts) and higher level (Autonomous Republic of Crimea, oblasts, cities of Kyiv and Sevastopol) (Constitution of Ukraine, 1996; State Statistics Service of Ukraine).

Another territorial and administrative division in Ukraine is the territorial community – residents united by permanent residence within a village, town, city, which are independent administrative-territorial units, or voluntary association of residents of several villages, towns, cities, which have a single administrative centre (according to the Law of Ukraine "On Local Self-Government"). According to Article 140 of the Constitution of Ukraine, a territorial community is defined as residents of a village, settlement, city, or a voluntary association of residents of several villages into a rural community (Constitution of Ukraine, 1996). As of 2021, there are 1,469 communities in Ukraine formed by uniting villages, settlements, and cities. Territorial community, the administrative centre of which is the city, is an urban territorial community, the centre of which is defined as an urban-type settlement – settlement, the centre of which is determined by the village – rural. For the sake of this study, urban areas will include the territories of urban territorial communities, while rural areas will include the territories of rural and settlement territorial communities (Fig. 1).

a)



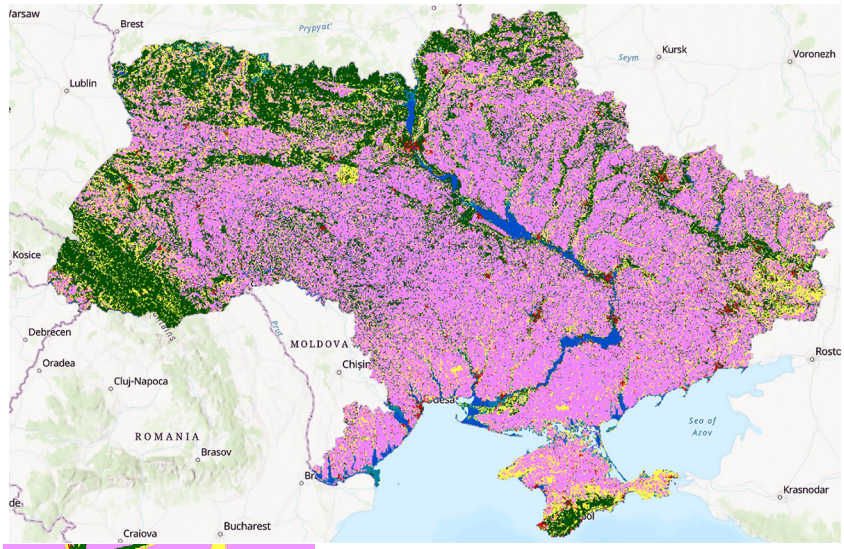
b)

------ State border of Ukraine;
------ Regional (oblast) borders;
------ Territorial community borders;
------ Rural and settlement TC*;
------ Urban TC*;
------ State (gov.) and other territories;
*TC – territorial community

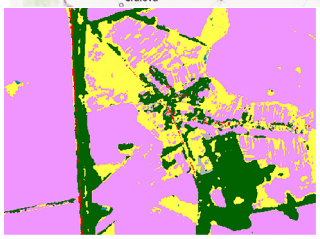
Figure 1. *Geographical position (b) of Ukraine and its administrative-territorial division (a)*

Data sources. In this work, to study the earth's surface of Ukraine at the level of territorial communities, we used the product of the European Space Agency (ESA) WorldCover 2020 with global coverage with a resolution of 10 m. The classification method was based on spectral images from the Sentinel-1 and Sentinel-2 spacecraft (Fig. 2).

a)



b)



On the picture presented classified territories of Velyka Horbasha village, Chernyakhiv territorial community, Zhytomyr oblast

Forested areas – green;
Shrubs – yellow
Meadows, hayfields – lime
Cultivated land – pink
Built-up land – red
In more detail – Table 1

Figure 2. *Results of the European Space Agency's ESA WorldCover 2020 Earth Cover Classification for Ukraine (a) and for small village (b)*

ESA WorldCover's global product was created based on the developments of GlobCover and CCI Land Cover from the European Space Agency (Table 1). The algorithm used to create the ESA WorldCover product was based on the analysis of the dynamic annual map of multispectral images Sentinel-2, and radar data with synthetic aperture (SAR) of the C-band spacecraft Sentinel-1 (Arino *et al.,* 2008; Buchhorn *et al.,* 2020; Camp-Valls *et al.,* 2011). The WorldCover product prototype was statistically tested using an independent test data set. The verification was in line with the recommendations for the CEOS (Earth Observation Satellite Committee) verification (Phase 3). The results of the inspection showed that the overall accuracy of the WorldCover product is 74.4±0.1% for 2020. In terms of soil types, wood cover and snow/ice, classes of agricultural land, water bodies and bare/sparse vegetation were highly accurate, while classes of shrubs, grasses and mosses/lichens were mapped with less accuracy.

***Table 1**. Characteristics of earth cover classes according to the methodology of the European Space Agency ESA WorldCover 2020*

Code	Name	Feature
10	Forested areas	This class of land cover includes any geographical area in which there are forested areas with a cover of at least 10%. Areas planted with trees, such as protective forest belts, parks, and orchards, are included in this class
20	Shrubs	This class includes any geographical area dominated by natural shrubs with a cover of 10% or more. Shrubs are defined as woody perennials with stable and woody stems and without any defined main stem less than 5 m tall
30	Meadows, hayfields, pastures	This class includes any area dominated by natural herbaceous plants (plants without a stable stem or shoots above the ground and without a clear solid structure) meadows, prairies, steppes, savannas, pastures with a coverage of 10% or more, regardless of the type of human and/or animal activity
40	Cultivated lands	Land cover covered with cultivated annual crops. Greenhouses are considered built up
50	Built-up land	Land cover, which houses, roads, railways, and other anthropogenic objects. Houses include both residential and industrial buildings. Asphalt and concrete roads are included in this class
60	Rarefied vegetation	Land cover with open ground, sand, or stones, never has more than 10% of vegetation cover at any time of the year
70	Snow and ice	This class includes any geographical area that is permanently covered by snow or glaciers
80	Permanent reservoirs	This class includes any geographical area covered by water bodies for most of the year: lakes, reservoirs, and rivers. There can be both fresh and salt water. In some cases, water can freeze for part of the year, but not less than 9 months per calendar year
90	Grassy wetlands	Land cover dominated by natural grassy vegetation (10% or more cover), which is constantly or regularly flooded with fresh or salt water
95	Mangrove thickets	Taxonomically diverse, salt-resistant trees and other plant species thrive in tidal protected tropical coastal areas, islands, and estuaries
100	Moss and lichen	Land covered with lichens and/or mosses. Lichens are complex organisms formed because of a symbiotic association of fungi and algae

***Source**: Arino et al., 2008*

RESULTS AND DISCUSSION

The product of the classification of the Earth's cover of our planet is the observed physical cover of the Earth, divided into classes based on a certain method. Today we can distinguish two main methods of monitoring the state and dynamics of changes in land cover: field surveys and analysis of remote sensing. The first method is exceptionally reliable but requires large investments for scaling (coverage of territories at the regional, national, and global levels). The basis for the second method is the processing of information from remote Earth sensing using ground, aviation, or space survey. The method of remote sensing analysis has several features: 1) global scale; 2) a deep time series of observations allows tracking changes over time (Landsat products have been available since 1972); 3) enables operational monitoring of any geographical area; 4) low quality compared to field surveys.

In this work, we used the results of the ESA WorldCover product to analyse the state and structure of the earth's cover in Ukraine. The results of such an analysis prove the high reliability of the coincidence of official data and the results obtained (Table 2). Thus, the total area of the country obtained as a result of processing the ESA WorldCover product differs by 0.6% from the official data. A similar analysis conducted at the oblast level also shows a prominent level of coincidence in all oblasts except Mykolaiv (-2.4%), Kherson (-6.3%) and the ARC (-5.5%). Such significant deviations require more in-depth study.

***Table 2**. Land cover of Ukraine according to the results of processing the product ESA WorldCover, thousand hectares*

Type of land cove / Admin. unit	Forested areas	Shrubs	Meadows	Cultivated lands	Built-up land	Rarefied vegetation	Permanent reservoirs	Grassy wetlands	In total	Official Square (Rahman *et al.*, 2012)	Deviation
Vinnytsia	593	0.0	234	1736	25	11	29	11	2,640	2,651	-0.4
Volyn	840	0.1	438	659	11	13	15	38	2,015	2,014	0.0
Dnipropetrovsk	365	0.1	400	2,171	60	33	127	34	3,191	3,191	0.0
Donetsk	377	0.0	453	1,671	72	29	29	19	2,650	2,652	-0.1
Zhytomyr	1,338	0.0	560	981	19	33	14	38	2,984	2,983	0.0
Zakarpattia	871	0.2	240	141	15	4	4	1	1,276	1,278	-0.1
Zaporizhzhia	143	0.0	269	2,060	41	15	159	32	2,718	2,718	0.0
Ivano-Frankivsk	747	0.0	271	346	14	7	8	1	1,393	1,390	0.2
Kyiv	894	0.0	341	1,318	38	31	118	72	2,813	2,813	0.0
Kirovohrad	282	0.0	194	1,874	18	12	65	12	2,458	2,459	0.0
Luhansk	505	0.0	703	1,353	36	38	11	22	2,669	2,668	0.0
Lviv	903	0.0	519	708	27	8	11	6	2,182	2,183	0.0
Mykolaiv	140	0.1	301	1,838	37	12	48	26	2,402	2,460	-2.4
Odesa	290	0.1	441	2,236	62	29	169	109	3,335	3,331	0.1
Poltava	451	0.0	340	1,861	23	16	104	77	2,872	2,875	-0.1
Rivne	870	0.2	400	618	16	25	10	66	2,005	2,005	0.0
Sumy	672	0.0	375	1,285	15	10	13	15	2,384	2,383	0.0
Ternopil	295	0.0	135	922	14	7	8	3	1,383	1,382	0.1
Kharkiv	601	0.0	420	1,998	35	23	38	28	3,143	3,142	0.1
Kherson	105	0.0	319	1,850	34	39	217	100	2,666	2,846	-6.3
Khmelnytskyi	437	0.0	227	1,338	17	10	24	11	2,063	2,065	-0.1
Cherkasy	492	0.0	142	1,284	20	12	112	33	2,094	2,090	0.2
Chernivtsi	333	0.0	123	325	12	5	11	1	809	810	0.0
Chernihiv	1,034	0.0	545	1,487	13	16	23	70	3,189	3,187	0.1
ARC	300	0.0	777	1,201	64	48	39	47	2,477	2,620	-5.5
Ukraine	**13,977**	**1.1**	**9,194**	**33,272**	**767**	**493**	**1,414**	**872**	**59,991**	**60,355**	**-0.6**

Analysis of the land cover of Ukraine shows that over half of the country's surface (33,272 thousand hectares) is cultivated land (Fig. 3), i.e., land that is subject to tillage operations. At the same time, according to the official data of the State Statistics Service of Ukraine (SSSU), the area of cultivated land is 27,046.2 thousand hectares (Pyvovar & Pyvoar, 2021), i.e., the difference is 23%. This discrepancy is primarily due to the method of collecting information from agricultural enterprises and rural households of the SSSU. But cultivated land cannot be called agricultural, as part of the agricultural land belongs to the class of meadows and hayfields. 23.3% of the territory of Ukraine is forested areas, while according to official data of the SSSU this figure is 17.7%. The difference of 6% or 3,621 thousand hectares is because the forested areas according to ESA WorldCover include both forests and areas planted with trees (protective forest belts, parks, and orchards).

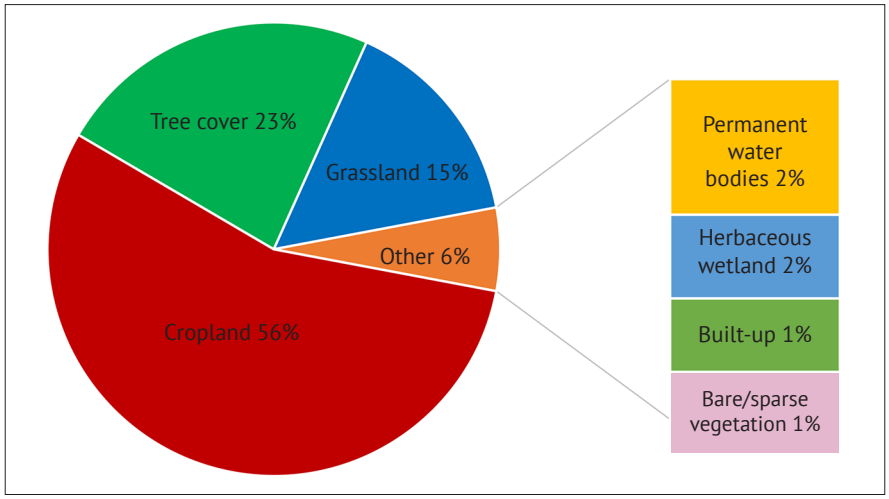


***Figure 3**. The structure of the land cover of Ukraine according to the product ESA WorldCover, 2020*

Rural areas are a multifunctional socio-spatial entity that functions as a synergistic unity of human, natural and economic potentials with their inherent characteristics: open natural space prevails over buildings, traditional rural way of life and primary processing of resources into goods or services to meet their own needs and ensure development (Pyvovar & Pyvovar, 2021). To divide rural and urban areas, we used the classification of territorial communities of Ukraine into urban, settlement and rural. At the same time, urban and rural communities are the basis of rural areas, and urban communities, respectively, urban areas. As a result of combining ESA WorldCover land cover data and landfills of territorial communities of Ukraine, we structured the territories of oblasts into rural and urban areas (Figure 4).

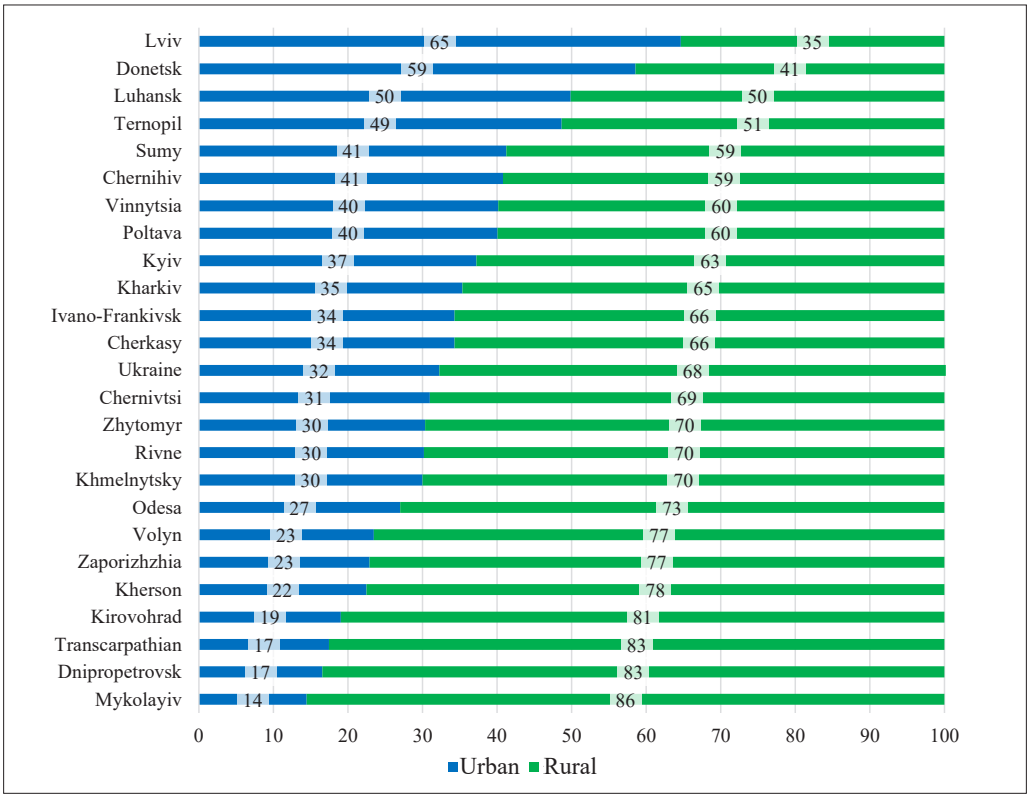


***Figure 4**. The structure of the territories of Ukraine at the regional level according to the product ESA WorldCover, 2020*

According to Figure 4, 32% of the surface of Ukraine can be attributed to urban, respectively 68% – to rural. The largest share of rural territories is represented in such oblasts as Mykolaiv (86%), Dnipropetrovsk (83%) and Zakarpattia (83%). The oblasts with the highest proportion of urban areas are Lviv (65%), Donetsk (59%) and

Luhansk (50%). Geographical features and location of oblasts are not factors that affect the distribution structure of rural and urban areas.

Forested areas are parts of the land cover where the share of tree cover is not less than 10%. Such areas include forests, protective forest belts, agricultural orchards, forest parks. According to ESA WorldCover data, 23.3% of Ukraine's territory is covered by forested areas. According to official data from the SSSU, the same figure is 17.7% (Fig. 5) (Shubravska & Prokopenko, 2016). The difference of 6% or 3621 thousand hectares are forest belts, orchards, parks, and other forested areas. Forests in Ukraine are concentrated in Polissia and the Ukrainian Carpathians (Fig. 6).

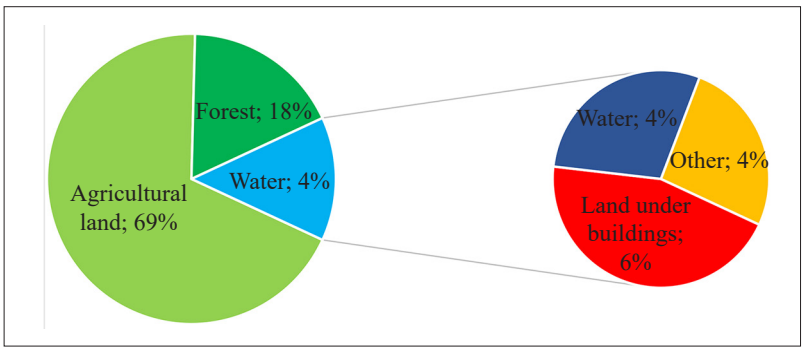


Figure 5. *The structure of the land cover of Ukraine according to the official data from the SSSU*
Source: *(Shubravska & Prokopenko, 2016)*

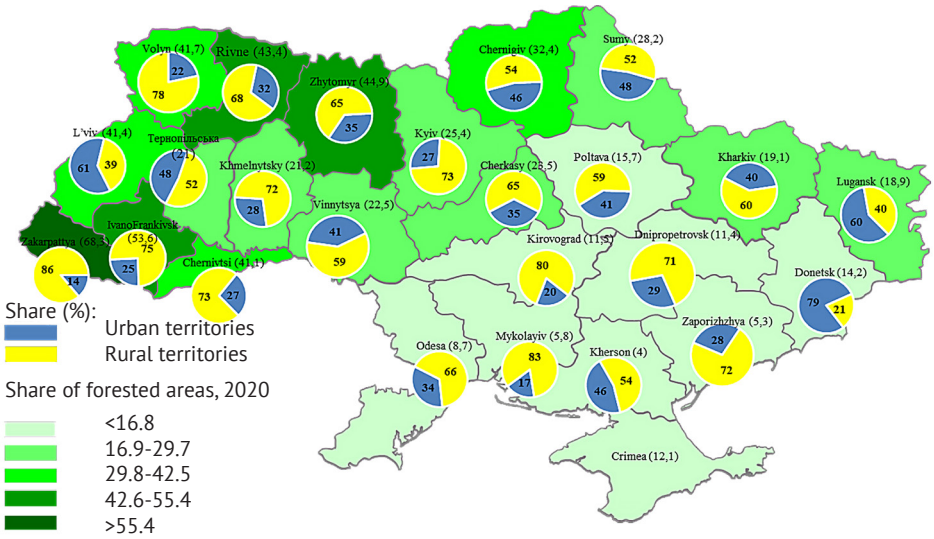


Figure 6. *Structure and distribution of forested areas of Ukraine at the regional level according to the product ESA WorldCover, 2020*

The most forested areas are Zakarpattia (68%), Ivano-Frankivsk (54%) and Zhytomyr (45%) oblasts, while the least forested are Kherson (4%), Zaporizhzhia (5%) and Mykolaiv (6%) oblasts. In general, 71% of forested areas are rural and 29% are urban. The oblasts with the largest share of forested areas in rural areas are Zakarpattia (86%), Mykolaiv (83%), Kirovohrad oblast (80%), and the smallest – Ternopil (43%), Luhansk (40%), Lviv (39%).

15% of the territory of Ukraine is covered with meadows, hayfields, and pastures – a class of land cover, which includes areas with vegetation of 10% or more, regardless of the type of human and/or animal activity. Meadows – a plot of soil in conditions of sufficient or excessive moisture, covered with perennial herbaceous plants, mainly cereals and sedges. It is usually used as pasture for livestock and as hayfields. All meadows are characterised by the presence of grass and turf. Hayfields (hayfields) are also called agricultural lands, the vegetation of which is constantly used for hay production. This is one of the main types of fodder base for livestock in the post-vegetation period and in general during stall keeping. Pastures – land covered with vegetation used by animals (livestock, poultry) as forage. 66% of the territories of this class fall on rural areas, respectively on urban areas – 34%. This class of territories is a vital part of the functioning and restoration of territorial ecosystems. Most of them are concentrated in Luhansk (26%), Lviv (24%) and Volyn (22%) oblasts, while the least in Cherkasy (7%), Kirovohrad (8%) and Vinnytsia (9%) oblasts (Fig. 7).

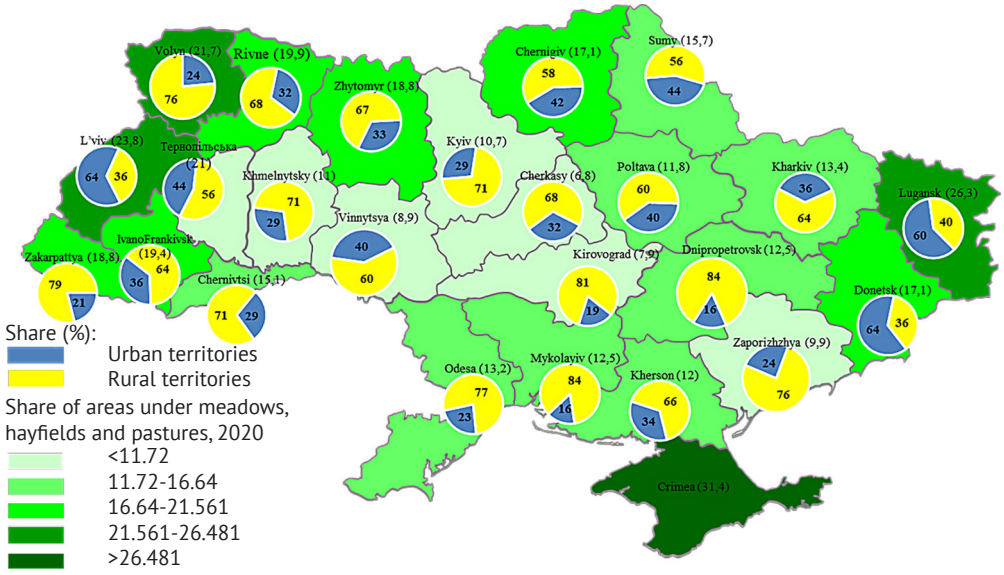


***Figure 7**. Structure and distribution of the territories of Ukraine under meadows, hayfields and pastures at the regional level according to the ESA WorldCover product, 2020*

Cultivated land – land that is systematically cultivated and used for growing crops. However, according to the ESA WorldCover methodology, indoor land (greenhouses, hotbeds, and insulated nurseries) does not fall into this category. Given the small share of closed land (greenhouses), cultivated land can be compared with the level of ploughing. In total, 55% of Ukraine's territory is cultivated, while according to the Food and Agriculture Organisation (FAO), the level of ploughing in Ukraine is 53.9%. For comparison, in Poland this figure is 36.5%, in Germany 34.1%, in the United States – 17.5% (Nguyen & Liou, 2019a). According to ESA WorldCover, 70% of rural areas are cultivated and 30% in urban areas. The leaders among the oblasts with the largest share of cultivated lands are Zaporizhzhia (76%), Kirovohrad (76%), Mykolaiv (77%). Therewith, in rural areas, ploughing is 80%, 81% and 87%, respectively (Figure 8). Respectively, the lowest share of cultivated lands was in Rivne (31%), Ivano-Frankivsk (25%) and Zakarpattia (11%) oblasts with the corresponding level of ploughing of rural areas 72%, 49% and 70%.

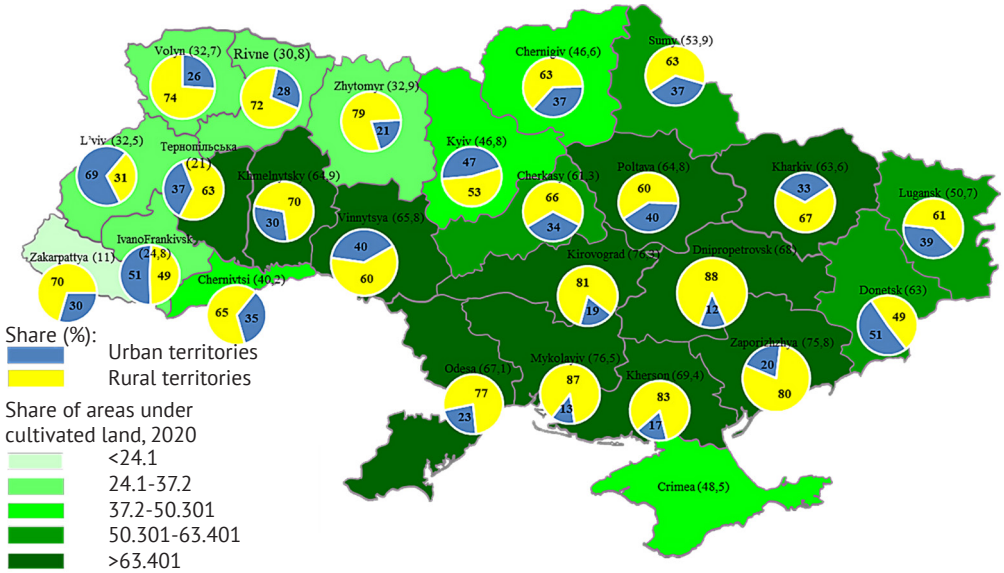


***Figure 8**. Structure and distribution of territories of Ukraine under cultivated lands at the regional level according to the ESA WorldCover product, 2020*

Permanent reservoirs are parts of the land cover with inland waters that are permanently or temporarily (not less than 9 months during the year) and have the form of various water bodies (streams, reservoirs). According to the analysis of ESA WorldCover data in Ukraine, about 2.3% of the territories are under open water, of which 71% are in rural territories and 29% in urban territories. The leading oblasts in terms of surface

water supply were Cherkasy (5%), Zaporizhzhia (6%) and Kherson (8%) with the respective shares of 64%, 63% and 82% in rural areas (Fig. 8). In turn, the oblasts with the smallest share of open water areas are Zhytomyr (0.5%), Luhansk (0.4%) and Zakarpattia (0.3%) oblasts with the respective shares of rural areas at 77%, 33% and 46 % (Fig. 9).

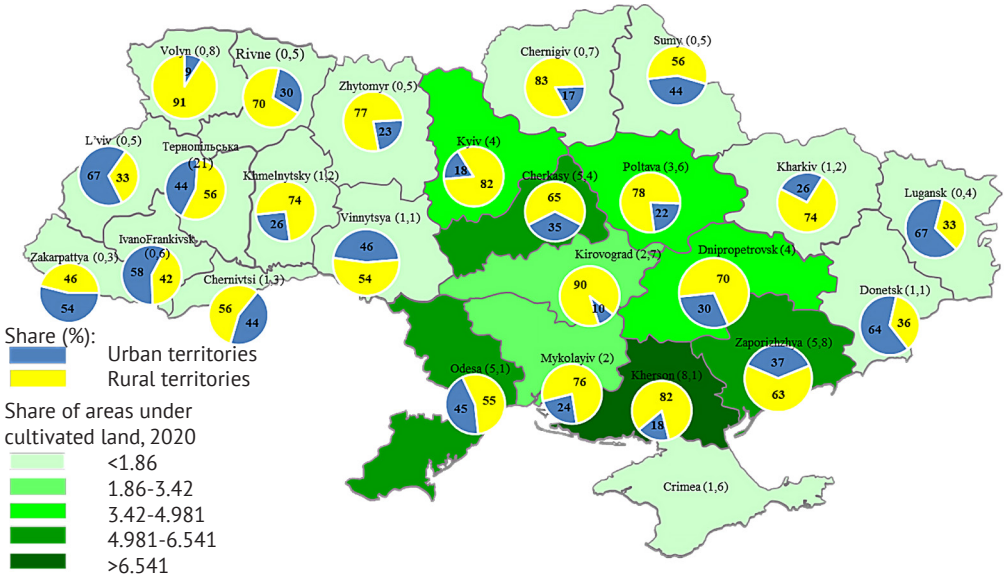


***Figure 9**. Structure and distribution of territories of Ukraine under open waters at the regional level according to the product ESA WorldCover, 2020*

The use of the product ESA WorldCover, 2020 for the analysis of land cover classes of Ukraine has shown high recognition results at two types of levels: national and regional, rural, and urban. However, some minor discrepancies were noted, namely the fact that some recognition results, especially for small plots (less than 1 hectare), do not correspond to real data. Furthermore, some fallow lands were incorrectly classified as wetlands. Some of the forested areas in certain areas have been classified as swamps or meadows, which we believe is due to fluctuations in humidity. The class of human infrastructure facilities (settlements, industrial facilities) is still difficult to classify. Also, high heterogeneity, a combination of small artificial (buildings, roads) and semi-natural objects (homesteads, lawns, wastelands) in many cases is not classified correctly.

In recent years, several scientific papers have appeared on the analysis and use of terrestrial classification products (Lyalko *et al.,* 2006; Lyzhnyk & Svidzinskaya, 2014). A significant amount of European research focuses on the analysis of coverage, which is the basis for land management in the European Union. The publications focus on the issues of land cover classification algorithms and data verification methods (Zibtsev *et al.,* 2015). Similar works were carried out for the territory of Ukraine to improve the quality and accuracy of data. Based on the use of this data, several new data processing methods using machine leaning methods have been created (Kusul *et al.,* 2015). At the same time, the question of further application of classification data for the development of regional policy based on the concept of sustainable development is still open.

CONCLUSIONS

The classification of land cover based on satellite imagery is vital in decision-making in business and in regional and national governance. Businesses receive up-to-date information on the state of the natural object – the object of production, while state and regional authorities can use this information for strategic development planning, development of support programs, etc. In general, 68% of Ukraine's territory is rural, with 64% of forested areas, 70% of cultivated lands, 71% of open water areas and 66% of meadows, pastures, and hayfields. The analysis shows that Ukraine is characterised by a high degree of land development. Thus, in 2020, 55.5% of their total area was cultivated. A characteristic feature of Ukraine's land structure is a significant share of land (15.3%) under meadows, hayfields, and pastures, which play a significant role in restoration and preservation of groups and are an essential element in the functioning of regional ecosystems. Forested areas by their purpose and location can perform several important functions, the most important being water protection, preservation, sanitation, recreation, and meeting the needs of society in wood. The level of afforestation in Ukraine is 23.3%, with 17.7% of the territory being forests and the other 6% being protective forest belts, orchards, and arboretums. At the same time, the level of afforestation in Ukraine is one of the lowest among the EU countries, where it is 38%. In Ukraine, the share of surface waters covering the geographical area is 2.4% and the distribution of these waters between oblasts is uneven. Thus, the leading oblasts in terms of surface water supply in 2020 were Cherkasy (5%), Zaporizhzhia (6%) and Kherson (8%). In the same period, the lowest level of surface water supply was found in Zhytomyr (0.5%), Luhansk (0.4%) and Zakarpattia (0.3%) oblasts.

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Аналіз сільських територій України на основі продукту ESA WorldCover 2020

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Анотація. На сьогодні ГІС технології проникають в різні сфери соціально-економічного буття людства. В цій статті на основі ГІС технологій було проаналізовано основні класи земного покриву України з подальшим поглибленим вивченням в розрізі областей та сільських і міських територій. Відповідно до результатів цього дослідження на основі даних ESA WorldCover, 32 % територій України можна віднести до міських, відповідно 68 % – до сільських. В загалом, проведений аналіз демонструє що Україна характеризується високим ступенем освоєння земельного фонду, так на землі, які піддавались культивації у 2020 році припадало 55,5 % його площі. Сільські території на 70 % складаються з культивованих, міські території – 30 %. Лідерами серед областей із найбільшою часткою культивованих угідь є Запорізька (76 %), Кіровоградська (76 %), Миколаївська (77 %) при цьому на сільських територіях розорень становить 80 %, 81 % та 87 % відповідно. Характерною рисою структури земель України є суттєва частка земель (15,3 %) під луками, сіножатями та пасовищами, що виконують важливу роль як у процесі відновлення та збереження гуртів так і як важливий елемент функціонування регіональних екосистем. 66 % територій цього класу припадає на сільські території, відповідно на міські – 34 %. Найбільше їх зосереджено у Луганській (26 %), Львівській (24 %) та Волинській (22 %) областях. Рівень залісненості території України становить 23,3 %, причому 17,7 % територій це ліси, а інші 6 % – захисні лісосмуги, фруктові сади та дендропарки. На сільські території припадає 64 % заліснених територій. До найбільш заліснених територій відносяться Закарпатська (68 %), Івано-Франківська (54 %) та Житомирська (45 %), тоді як найменш залісненні Херсонська (4 %), Запорізька (5 %) та Миколаївська (6 %). В загалом 71 % заліснених територій припадає на сільські території та відповідно 29% – на міські. В Україні частка поверхневих вод, що покривають географічну територію становить 2.4 %, з яких 71 % припадає на сільські території, відповідно 29 % – на міські. Областями-лідерами по забезпеченню поверхневими водами були Черкаська (5 %), Запорізька (6 %) та Херсонська (8 %) з відповідними частками, що припадають на сільські території 64 %, 63 % та 82 % (Рис. 8.). В свою чергу до областей із найменшою часткою територій під відкритими водами відносяться Житомирська (0.5 %), Луганська (0.4 %) та Закарпатська (0.3 %) області з відповідними частками, що припадають на сільські території 77 %, 33 % та 46 %

Ключові слова: сільська місцевість, ГІС-технології, земний покрив, культивовані землі, заліснені території

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The Role of Fiscal Mechanism in Regulation of Households' Investment Activity in EU Countries and in Ukraine

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Abstract. The fiscal mechanism, which serves as a means of implementing fiscal policy, thanks to the organisation of fiscal relations by changing the mechanisms for the formation of budget revenues and expenditures, directs the established fiscal interrelationships, manages the channels of passage and directions of fiscal flows, specifies the proportions of the distribution of financial resources and, thus, ensures regulation investment activity of households. For Ukraine, in the context of its European integration aspirations, the study of the impact of the components of the fiscal mechanism, namely taxes, on the implementation of household investments in the EU countries becomes particularly relevant. Therefore, the purpose of this study was to form a holistic view of the elements of the fiscal mechanism that cause changes in investment processes at the micro level in the EU countries and in Ukraine, as well as to perform correlation and regression analysis to identify the quantitative impact of the fiscal mechanism on the investment activity of households. During the study, the Ukrainian and European practices of taxation of the population is considered and the total tax burden on individuals in the EU countries and in Ukraine is calculated. A correlation and regression analysis of the impact of elements of the fiscal mechanism on household investments in the EU and Ukraine was carried out, which showed that the scale of their taxation had the greatest impact on the implementation of citizens' investments, while the overall tax burden played a secondary role in regulating investment processes at the micro level. As a result of the study, it was proved that in Ukraine, to increase the investment activity of households, it is necessary to consider the practices of EU countries and improve those elements of the fiscal mechanism that have the greatest regulatory impact on investment. Such a part of the fiscal mechanism is taxes, especially in terms of effective provision of tax benefits

Keywords: budget, taxes, investment, individual, tax burden

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INTRODUCTION

In modern conditions, states use the fiscal mechanism to implement fiscal policy, which is designed not only to determine the sources of formation and use of budget resources, but also to influence investment processes at the micro level. The influence of the fiscal mechanism on the investment activity of households is carried out through its structure and the orientation of its components to solve particular tasks and achieve a real investment effect, which occurs due to financial resources that are formed, distributed, and used to meet the investment needs of the population. The fiscal mechanism regulates the size of potential sources of investment resources of households, namely by dividing income between consumption, savings, and investment. Therefore, the investment activity of citizens depends on the correct choice and effective use of various elements of the fiscal mechanism.

The COVID-19 pandemic, and later Russia's full-scale invasion of Ukraine, highlighted the critical role of the fiscal mechanism in maintaining the life of households and ensuring their functioning. Extremely unfavourable events led to the closure of enterprises, a decline in business activity and a contraction of the labour market. The reduction in the number of jobs and falling incomes of individuals against the background of uncertain development prospects led to a considerable reduction in consumption and investment. If at the beginning of the pandemic and military operations, the fiscal mechanism ensured the restoration of consumption, then in the future, to overcome the adverse consequences of the coronavirus crisis and war, it should contribute to the activation of household investment, which is an essential prerequisite for the sustainable development of the Ukrainian economy.

Currently, issues of quantitative analysis of the relationship between the components of the fiscal mechanism and household investments in the context of Ukraine's European integration aspirations are being updated. Understanding the quantitative impact of the fiscal mechanism on the investment activities of individuals is necessary to develop sound fiscal decisions that will contribute to the achievement of investment goals and will not lead to a catastrophic reduction in taxes and/or increase in budget expenditures.

Many studies cover certain aspects of the influence of the components of the fiscal mechanism on the investment activity of households in the world and Ukrainian scientific literature. Thus, J. Alves (2019) investigated the impact of the structure of the tax system on investment dynamics in the short and long term, but by OECD countries, and not with a specification on household investment. S. Fedorov (2017), O.V. Ozerchuk & L.B. Rainova (2014), F. Zhuravka et al. (2021) focused their attention on income taxation of the population, but mostly in the social context, rather than in the investment one. I.V. Ped et al. (2012), O.Ye. Naidenko (2015) considered property taxation of households, but in terms of the impact on investments already made, and not on future ones. T.I. Yefymenko & A.M. Sokolovska (2013), I. Verkhovod et al. (2020), S.H. Operenko (2018), A.M. Sokolovska (2006) focused on determining the tax burden on individuals and its impact on various segments of the population, including in terms of making investment decisions. S. Van Pays & S. James (2010), L.M. Akimova et al. (2018), A. Celani et al. (2022) were looking for tax incentives that can effectively influence the activation of household investment. Despite a considerable number of studies on the role of individual components of the fiscal mechanism in regulating investment activity of the population, they contain only certain elements of quantitative analysis of such influence, which allow only indirectly and fragmentarily judging the relationship between the fiscal and investment.

The purpose of this study was to form a holistic view of the elements of the fiscal mechanism that cause changes in investment processes at the micro level in the EU countries and in Ukraine, as well as to perform correlation and regression analysis to identify the quantitative impact of the fiscal mechanism on the investment activity of households.

MATERIALS AND METHODS

The research materials are scientific literature, data from official websites of public authorities and works of modern scientists, containing materials that describe the components of the fiscal mechanism, as well as serve as a way to create initial ideas and initial concepts about the role of elements of the fiscal mechanism in regulating the investment activity of households in the EU countries and in Ukraine. The methodological basis of the research is determined by the application of several general scientific and private scientific, theoretical and empirical methods of cognition based on the categories and principles of dialectics. The dialectical method of cognition made it possible to consider the influence of the components of the fiscal mechanism on investment processes at the micro level.

The use of theoretical research methods allowed delving into the very nature of the fiscal mechanism, to identify its components, namely taxes, which can affect the implementation of investments by households. The main theoretical methods of knowledge used in the study include analysis – to distinguish groups of taxes paid by individuals and characterise them in the context of investment development of households in the EU countries and in Ukraine; synthesis – to combine all tax payments from the population into a single taxation system, which positively or negatively affects investments by citizens in EU countries and Ukraine; induction – to make inferences regarding the impact of the population taxation system, considering its components, on investment processes at the household

level in the EU countries and in Ukraine; deductions – to distinguish the regulatory function of certain groups of taxes within the population taxation system for stimulating or restraining their investment activity in the EU countries and in Ukraine; generalisation – to identify and record the main facts regarding the impact of taxes on the investment development of households in the EU countries and in Ukraine; abstraction – to isolate and turn into an independent object of consideration of individual parties and characteristics of taxes in the context of their impact on investment processes at the micro level; specification – to specify the main elements of taxes on the population in the EU countries and in Ukraine; comparison (comparativism) – to determine the general and distinctive features of taxes as stimulators or destimulators of investments in the EU countries and in Ukraine.

The application of empirical research methods allowed performing a comparative analysis of the impact of the components of the fiscal mechanism on the investment development of households in the EU countries and in Ukraine, as well as to summarise and describe the results. The main empirical methods of cognition, which were used in the study include monitoring – to monitor the taxes paid by the population in the EU countries and in Ukraine, the results of which were used to explain the impact of individual tax payments on the investment activity of households; measurement – for calculating the total tax burden on individuals in the EU countries and in Ukraine and justifying its role in making investments by households; correlation-regression analysis – for building and evaluating an economic-mathematical model in the form of a regression equation, which expresses the dependence of the result characteristic (household investments) on one or more characteristic factors (taxes paid by the population and the total tax burden on citizens); study and generalisation of experience – to investigate the practices of the EU countries and Ukraine regarding the use of tax benefits to increase the investment activity of households. The methods used in the study did not exclude the possibility, in some cases, of simply stating the facts to give the relevant reasoning of the necessary evidentiary force.

The study was conducted as a logical process that covered two main stages – theoretical and empirical. The theoretical stage of the study included the collection, systematisation, and generalisation of facts regarding the influence of the elements of the fiscal mechanism on the investment activity of households in the EU countries and in Ukraine. At this stage, the Ukrainian and European practices of taxation of the population are considered in the context of the impact on investment processes at the micro level. The empirical stage of this study included the calculation of the total tax burden on individuals and correlation-regression analysis of the impact of the elements of the fiscal mechanism on the investment development of households in the EU countries and in Ukraine, with the knowledge and formulation of corresponding conclusions.

RESULTS AND DISCUSSION

The fiscal mechanism functions as a set of interconnected elements that can regulate the investment activity of households to varying degrees. The authors of this paper believe that the influence of the fiscal mechanism on the implementation of investments by individuals can occur thanks to taxes and state transfers. Since state transfers are received by the most vulnerable and low-income sections of the population, it is unlikely that a positive investment effect will be achieved as a result of their provision. Accordingly, taxes remain the main fiscal tool for influencing household investments. As J. Alves (2019) points out, income taxes and social security contributions reduce the aggregate demand of the population, and therefore reduce the demand for goods and services, which can have a decisive impact on new investment decisions.

Ukraine has chosen the path of European integration; therefore, it is worth investigating the influence of the components of the fiscal mechanism on the investment activity of households in comparison with EU countries. This allows not only determining the national specifics of the functioning of the fiscal mechanism, but also borrowing the leading practices of European states to improve its components in terms of regulation of investment processes.

First, for the purposes of this study, all taxes paid by individuals were divided into several conditional groups as follows:

1) taxes on income and capital gains, which include personal income tax, and in some European countries – a separate tax on capital gains;

2) tax payments of a social nature, which include one or more payments for various types of social insurance (medical, pension, in case of loss of working capacity, in case of unemployment, in case of an accident at work, etc.);

3) property taxes, which include taxes on movable and immovable property, as well as property transfer taxes;

4) other taxes, which include tax payments of an environmental, administrative, and tourist nature.

Taxes on income and capital gains in EU countries and in Ukraine include taxation of labour income, taxation of passive income and taxation of capital gains (Table 1).

***Table 1**. Personal income taxes in the EU and Ukraine*

Country	Labour income	Passive income	Capital gains
Austria	S L: 0-55% TB	27.5% TB	27.5% TB
Belgium	S L: 20-50% TB; R/L L: 0-9% TB	30% TB	BR PIT
Bulgaria	S L: 10% TB	5%, 8%, and 10% TB	10% TB
Greece	S L: 9-44% TB	5% and 15% TB	15% TB
Denmark	S L: 12.1-15.0% TB; R/L L: municipal tax – 24.982% TB; labour market tax – 8% TB	BR PIT	BR PIT
Estonia	S L: 20% TB (base rate); 10% and 7% TB (reduced rates)	BR PIT	BR PIT
Ireland	S L: 20-40% TB	25% and 33% TB	33% TB
Spain	S L: 19-47% TB	19-26% TB	26% TB
Italy	S L: 23-43% TB; R/L L: regional tax – 1.23-3.33% BU; municipal tax – 0-0.8% TB	26% TB	26% TB
Cyprus	S L: 0-35% TB	They are taxed only with a special defence contribution	20% TB
Latvia	S L: 20-31% TB	0% and 20% TB	20% TB
Lithuania	S L: 20 and 32% TB	15% TB	20% TB
Luxembourg	S L: 8-42% TB	20% TB	BR PIT
Malta	S L: 0-35% TB	Not subject to PIT	8% or 10% TB
Netherlands	S L: 9.42–49.5% + fixed premium	Not subject to PIT	Usually not applied
Germany	S L: 0-45% TB	25% TB + added solidary tax	25% TB + added solidary tax
Poland	S L: 17-32% TB	19% TB	19% TB
Portugal	S L: 0-48% TB	28% TB	28% TB
Romania	S L: 10% TB	5% and 10% TB	BR PIT
Slovakia	S L: 19 and 25% TB	7% TB	BR PIT
Slovenia	S L: 16-50% TB	27.5% TB	27.5% TB, which decreases according to the duration of the asset retention period
Hungary	S L: 15% TB	0%, 10%, and 15% TB + social tax (in some cases)	15% TB + social tax (in some cases)
Finland	S L: specific rate 8-11,351.5 EUR + ad valorem rate 6-34% TB; R/L L: 16.50-23.50% TB	30% TB (and 34% of income exceeding EUR 30,000 per year)	30% TB (and 34% of income exceeding EUR 30,000 per year)
France	S L: 0-45% TB + an added 3% rate on a part of high incomes	12.8% TB + added social tax	12.8% TB + added social tax + exclusive 4% high income tax
Croatia	S L: 20% and 30% TB; R/L L: 0-18% TB	10%, 20%, and 30% TB + utility tax (0-18%) + social insurance contribution	10% TB + utility tax (0-18%)
Czech Republic	S L: 15% and 23% TB	15% and 35% TB	BR PIT
Sweden	S L: 0% and 20% TB; R/L L: 32% TB	30% TB	30% TB
Ukraine	S L: 18% TB	5%, 9%, and 18% TB	BR PIT

***Note**: S L – state level; R/L L – regional (local) level; TB – tax base; BR PIT – basic rate of personal income tax for the corresponding country*

***Source:** PricewaterhouseCoopers International Limited (2022)*

EU countries have progressive personal income tax rates in terms of taxation of labour income, except for Bulgaria, Romania, Hungary, which, like Ukraine, use a proportional rate. Low-progressive rates on personal income tax have been introduced in Estonia, Ireland, Lithuania, Poland, Slovakia, Croatia, the Czech Republic, and Sweden. According to S. Fedorov (2017), the predominance of low-progressive and progressive rates of taxation of labour income of the population of most EU countries is explained by the application of the principle of social justice, which makes provision for the collection of taxes according to the solvency of households, considering the risks of social tension, social conflict, negative socio-psychological impact on spheres of public life of particular importance.

On the one hand, to follow the principle of social justice, a low-progressive scale of taxation of personal income was introduced and applied in Ukraine during 2011-2014 (at rates of 15% and 17%) and during 2015 (at rates of 15% and 20%). However, the introduction of these low-progressive rates has demonstrated its inefficiency, as it has become one of the factors of shadowing citizens' incomes. On the other hand, according to O.V. Ozershuk & L.B. Rainova (2014), the use of a proportional personal income tax rate in conditions of considerable differentiation of Ukrainian household incomes led both to the transfer of the main tax burden to the low- and medium-income segments of the population, and to an uneven distribution of the tax burden between different sources of income. Furthermore, according to F. Zhuravka et al. (2021), the problem of shadowing citizens' incomes due to the establishment of a proportional tax rate on labour income has not been solved because the development of informal processes at the micro level is influenced by several other factors, including economic, political and legal, demographic, socio-cultural, and individual.

Taxation of passive (investment) income of individuals in the EU countries differs significantly. In Malta and the Netherlands, such income is exempt from taxation, while in Cyprus, it is subject only to a special defence contribution. Many EU countries apply a proportional tax rate to passive income (Austria, Belgium, Italy, Lithuania, Luxembourg, Poland, Portugal, Slovakia, Slovenia, Sweden). Some EU countries (Bulgaria, Greece, Ireland, Latvia, Romania, Czech Republic), like Ukraine, use a differentiated tax rate. Some EU countries (Croatia, France, Germany, Hungary) apply social tax payments to passive income in addition to personal income tax (PricewaterhouseCoopers International Limited, 2022). Notably, in most EU countries, to create incentives for activating investment processes, passive income of citizens is taxed at lower rates than labour income. Although Ukraine applies differentiated tax rates to passive income, pursuing fiscal goals, most of such income is taxed at the base rate of 18%. Reduced personal income tax rates apply only to certain types of passive income (Tax Code of Ukraine, 2010):

— 5% – for income in the form of dividends on shares and corporate rights accrued by residents who pay corporate income tax (except for income in the form of dividends on shares, investment certificates paid by joint investment institutions);

— 9% – for income in the form of dividends on shares and/or investment certificates, corporate rights accrued by non-residents, joint investment institutions and business entities that are not payers of income tax.

In the EU countries, there is a specific taxation of capital gains, i.e., income received from the sale of various assets in comparison with the purchase price of such assets. Individual countries (Greece, Denmark, Ireland, Malta, Slovenia, Sweden) have a separate capital gains tax (PricewaterhouseCoopers International Limited, 2022). However, most states apply either the usual personal income tax rate or a special proportional tax rate to such income. In Ukraine, capital gains are considered ordinary income and are taxed at the usual personal income tax rate. An essential aspect of taxation of individuals in the EU and Ukraine is the collection of social tax payments on their labour income (Table 2).

***Table 2**. Social tax payments on personal labour income in the EU and Ukraine**

Country	Scale of taxation
Austria	≈ 21.23% TB
Belgium	≈ 13.07% TB
Bulgaria	13.78% TB
Greece	14.12% TB
Denmark	DKK 1,135. 8 per year
Estonia	do not cope
Ireland	4% TB
Spain	6.35% TB
Italy	≈ 10% TB
Cyprus	8.3% TB

Table 2, Continued

Country	Scale of taxation
Latvia	9.25% and 10.5% TB
Lithuania	6.98% and 19.50% TB
Luxembourg	12.20-12.45% TB
Malta	10% TB + fixed premium for high wages
Netherlands	EUR 9,808 per year
Germany	19.325% TB
Poland	13.71% TB
Portugal	11% TB
Romania	35% TB
Slovakia	13.4% TB
Slovenia	22.10% TB
Hungary	18.5% TB
Finland	≈ 10.89% TB
France	≈ 20–23% TB
Croatia	20% TB
Czech Republic	11% TB
Sweden	7% TB
Ukraine	do not cope

***Note**: TB – tax base*
***Source:** PricewaterhouseCoopers International Limited (2022)*

The burden of paying social insurance premiums in the EU countries is distributed in a certain proportion between employers and employees. Only the principle of parity participation in social insurance is still unchanged. The only exception is Estonia, where, as in Ukraine, only employers pay social insurance premiums. EU countries usually apply the ad valorem rate for such contributions, except for Denmark and the Netherlands, which have a specific rate.

In Ukraine, until the end of 2010, employees paid insurance premiums for mandatory state pension insurance, mandatory state social insurance in case of unemployment and mandatory state social insurance in connection with temporary disability. Employers, in addition to the above, paid an added insurance premium for mandatory state social insurance against industrial accidents and occupational diseases. However, since 2011, there have been changes in social insurance – all contributions to mandatory state insurance have been replaced by a single social contribution paid only by employers. The cancellation of payment of social insurance contributions by employees was justified by the fact that for objective reasons, the possibilities of substantially increasing the income of citizens from work based on ensuring economic growth and using conventional sources of increasing the income of employees in the near future are limited.

Property taxes paid by individuals in the EU countries can be considered in the context of two groups: property taxes and taxes on changes in property status. Property taxes are levied directly on particular properties and usually include movable property tax, real estate tax, and wealth tax. Taxes on changes in property status are levied not directly from particular property objects, but from those changes that occur with the latter over a certain period and have substantial financial and economic consequences for the owner of the property. I.V. Ped et al. (2012) include property sales tax, inheritance tax, and gift tax as such taxes.

Property taxes occupy a prominent place in the taxation of the population in the EU countries and in Ukraine (Table 3).

***Table 3**. Property taxes from individuals in the EU and Ukraine**

Country	Property taxes			Taxes on changes in property status		
	Real estate taxes	Movable property tax	Wealth tax	Taxes on property purchase and sale transactions	Inheritance taxes	Taxes on gifts
Austria	+	+	-	-	-	-
Belgium	+	+	+	-	+	+
Bulgaria	+	+	-	-	+	+

Table 3, Continued

Country	Property taxes			Taxes on changes in property status		
	Real estate taxes	Movable property tax	Wealth tax	Taxes on property purchase and sale transactions	Inheritance taxes	Taxes on gifts
Greece	+	+	-	+	+	+
Denmark	+	+	-	-	+	+
Estonia	+	+	-	-	-	-
Ireland	+	+	+	-	+	+
Spain	+	+	+	-	+	+
Italy	+	+	-	-	+	+
Cyprus	+	+	-	+	-	+/-
Latvia	+	+	-	-	-	+
Lithuania	+	+	-	-	+	-
Luxembourg	+	+	-	-	-	-
Malta	+	+	-	-	+/-	-
Netherlands	+	+	+	+	+	+
Germany	+	+	+	+	+	+
Poland	+	+	-	-	+	+
Portugal	+	+	-	-	+	+
Romania	+	+	-	-	-	-
Slovakia	+	-	-	-	-	-
Slovenia	+	+	-	-	+	+
Hungary	+	+	-	-	+	+
Finland	+	+	-	+	+	+
France	+	+	+		+	+
Croatia	-	+	-	+	+	+
Czech Republic	+	-	-	+	-	-
Sweden	+	+	-	-	-	-
Ukraine	+	+	-	-	-	-

Source: *PricewaterhouseCoopers International Limited (2022)*

In most EU countries, property taxation of both movable and immovable property is quite developed. Furthermore, most EU countries have introduced separate taxes on inheritance and gifts. Only certain countries (Belgium, Ireland, Spain, The Netherlands, Germany, France) practice collecting a wealth tax, the payers of which, as noted by O.Ye. Naidenko (2015), are wealthy citizens with an elevated level of well-being. This tax is levied on the value of the property after deducting the liabilities arising in connection with its ownership. In Ukraine, despite the official absence of a wealth tax, the latter is subject to transport tax and a tax on real estate other than land. This is because the payers of the transport tax in Ukraine are exclusively wealthy citizens because the object of taxation is passenger cars, the year of manufacture of which has passed no more than five years (inclusive) and the average market value of which exceeds 375 sizes of the minimum wages established by law on January 1 of the tax (reporting) year (Tax Code of Ukraine, 2010). Similarly, the tax on real estate apart from land is paid by wealthy individuals due to the existing reduction in the tax base of the object(s) of residential real estate, including their shares owned by an individual taxpayer (Tax Code of Ukraine, 2010). In many EU countries, the collection of wealth tax is justified by the principle of fair taxation, but the payers of such tax are representatives of the middle class, while really wealthy people who are well-versed in ways to avoid and evade taxation, usually do not pay this tax.

Apart from these tax groups, individuals in Europe pay several other taxes. These include church tax (Denmark, Germany, Finland), fish and hunting duty (tax) (Austria, Spain, Latvia, Germany, Portugal, Finland), dog tax (fee) (Austria, Estonia, Latvia, Luxembourg, Netherlands, Germany, Czech Republic, Finland), duty (fee) for driving on highways (Austria, Belgium, Denmark, Netherlands, Czech Republic, France), tourist tax (fee) (Spain, Czech Republic), waste removal (storage) fee (Greece, Italy, Czech Republic), environmental pollution fee (Estonia,

Spain, Lithuania, Netherlands, Slovenia, Hungary, Czech Republic), vehicle parking fee (Estonia) (PricewaterhouseCoopers International Limited, 2022). Some of these taxes and fees have analogues in Ukraine, e.g., environmental tax, tourist tax, and the fee for parking spaces for vehicles.

Furthermore, in EU countries, household taxes include a fee for the provision of public services in the form of stamp duty (Austria, Belgium, Denmark, Ireland, Italy, Malta), administrative (state) duty (Austria, Lithuania, the Netherlands), fees for licences to carry out certain types of activities (Belgium, Estonia, Spain, Italy, Latvia, Lithuania, Luxembourg, Germany, Hungary, Czech Republic), registration fee (Belgium, Estonia, Spain, Latvia, Luxembourg, Slovenia, Finland, France), construction permits (Spain, France), court fees (Portugal), etc. (PricewaterhouseCoopers International Limited, 2022). In Ukraine, there are also analogues of such tax payments, but according to the national budget classification, they are now classified as non-tax revenues (Order of the Ministry of Finance..., 2011). This is a controversial point because until 2011, fees for issuing licences and certificates, state registration of business entities were considered as part of internal taxes on goods and services (Order of the Ministry of Finance..., 2001). The state fee and court fee in the Law of Ukraine "On the Taxation System" were part of national taxes and fees (Law of Ukraine No. 1251-XII, 1991). Therefore, for the comparability of indicators of Ukraine and the EU countries, for the purposes of this study, all tax payments paid by the Ukrainian population will be attributed to taxes from individuals.

The review of taxes from individuals in the EU countries and in Ukraine shows that the Ukrainian tax system is quite loyal to the population because the number of taxes is small, and tax rates are moderate. However, an assessment of their tax burden provides an idea of the impact of taxation on household income and investment.

The authors of this paper agree with T.I. Yefymenko & A.M. Sokolovska (2013) on the fact that a generalised indicator that describes the level of tax burden on citizens is the ratio of taxes paid by them and other mandatory payments and income received (before tax). The total tax burden on individuals (TBt) can be found according to the following formula (1):

$$TB_t = \frac{TP_i}{I_i} \quad (1)$$

where TP_i are the tax payments from individuals (include all tax payments paid by individuals to the budget); I_i are the incomes of individuals (includes incomes of the population, except for social support and social transfers in kind, which are not subject to taxation).

The total tax burden on individuals calculated for the EU countries and Ukraine in 2011-2020 is presented in Table 4.

***Table 4**. Total tax burden on individuals in the EU and Ukraine in 2011–2020, %**

Country	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Luxembourg	55.24	59.82	61.77	60.36	60.96	66.72	62.72	73.62	69.75	70.71
Greece	35.89	51.46	60.78	61.29	64.06	67.25	65.80	62.22	56.63	50.57
Denmark	51.03	52.38	57.75	60.84	58.96	55.53	55.76	55.29	55.59	59.88
Austria	52.08	52.37	54.27	53.17	54.44	52.33	50.87	51.11	53.94	47.81
Netherlands	47.88	47.24	47.89	49.55	51.19	49.54	49.30	50.31	50.76	47.03
Sweden	49.27	45.32	45.80	48.25	49.82	52.07	51.67	50.49	50.65	46.92
Belgium	46.96	47.58	45.12	46.58	47.15	46.34	46.43	44.34	44.65	41.11
Germany	43.61	43.37	45.20	46.83	46.64	47.08	46.79	47.60	46.28	40.39
Romania	38.98	40.68	40.36	41.86	41.29	42.06	39.25	57.55	53.10	50.23
Hungary	42.69	42.60	43.88	44.49	44.29	43.50	46.95	46.16	42.87	38.06
Italy	40.88	43.31	44.51	43.49	44.04	43.55	43.22	43.51	43.58	39.80
Poland	39.37	41.06	40.96	40.86	42.38	42.22	43.87	46.48	46.31	42.20
Portugal	37.00	36.45	46.35	47.79	47.32	43.87	42.82	42.95	40.14	36.07
Finland	37.56	37.44	38.19	40.68	41.66	42.65	42.98	42.95	42.12	42.15
France	36.49	36.97	38.77	39.72	40.00	40.33	41.55	42.36	41.22	43.48
Ireland	40.87	43.01	42.32	43.23	39.97	37.84	36.10	33.77	35.63	33.74
Slovenia	36.30	35.73	34.86	36.26	36.29	37.71	39.33	39.65	38.38	35.99
Spain	31.97	33.58	35.14	38.41	38.53	38.16	37.07	37.21	37.42	33.48
Slovakia	29.79	28.03	32.04	33.64	35.81	38.01	37.31	37.49	35.90	32.46
Croatia	27.44	28.88	31.12	30.57	28.44	28.77	26.52	26.67	25.12	21.71
Lithuania	10.61	9.31	9.28	8.91	31.63	30.77	31.18	26.28	52.43	46.04
Czech Republic	24.94	24.48	24.37	24.50	24.94	25.35	25.57	25.78	25.84	25.02

Table 4, Continued

Country	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Latvia	27.01	27.39	28.26	25.35	23.94	22.39	22.66	22.78	21.83	22.97
Malta	19.53	19.42	20.12	19.51	19.29	21.25	22.84	25.53	26.01	25.32
Bulgaria	14.07	15.83	16.40	17.53	17.31	20.78	20.09	22.49	20.21	19.33
Estonia	18.20	18.35	17.79	17.92	16.42	16.01	15.59	14.37	14.42	15.88
Cyprus	7.95	7.88	7.54	8.48	9.25	8.96	9.35	9.42	10.11	9.64
Ukraine	9.85	10.33	9.64	10.10	11.84	12.60	13.29	13.28	13.60	13.56

Source: *Eurostat (n.d.), Official website of the Ministry of Finance of Ukraine (n.d.), Official website of the State Statistics Service of Ukraine (n.d.)*

During 2011-2020, the total tax burden on the population in most EU countries and in Ukraine tended to increase. The exception was 2020, when, given the spread of the COVID-19 pandemic, personal income tax and social insurance contribution rates were reduced in some EU countries, namely in Belgium, France, Italy, and Poland (Rudenko *et al.*, 2022).

Notably, the lowest level of tax burden on citizens is observed in those EU countries where a proportional or low-progressive rate on personal income tax is introduced. However, in such countries, the main income tax on individuals does not perform its strategic task of fair redistribution of income between segments of the population. Thus, the burden of paying tax is shifted towards citizens who do not have high incomes, while wealthy individuals receive the most comfortable conditions for income taxation. The principle of equality under such conditions works successfully in one area: wealthy citizens and workers who receive the minimum wage pay the same income tax.

In Ukraine, the total tax burden on citizens in the period under study tended to increase due to the introduction of the military levy, higher rates, and expansion of the tax base for personal income tax. In general, over the past decade, the average total tax burden on individuals in European countries has differed considerably (Fig. 1).

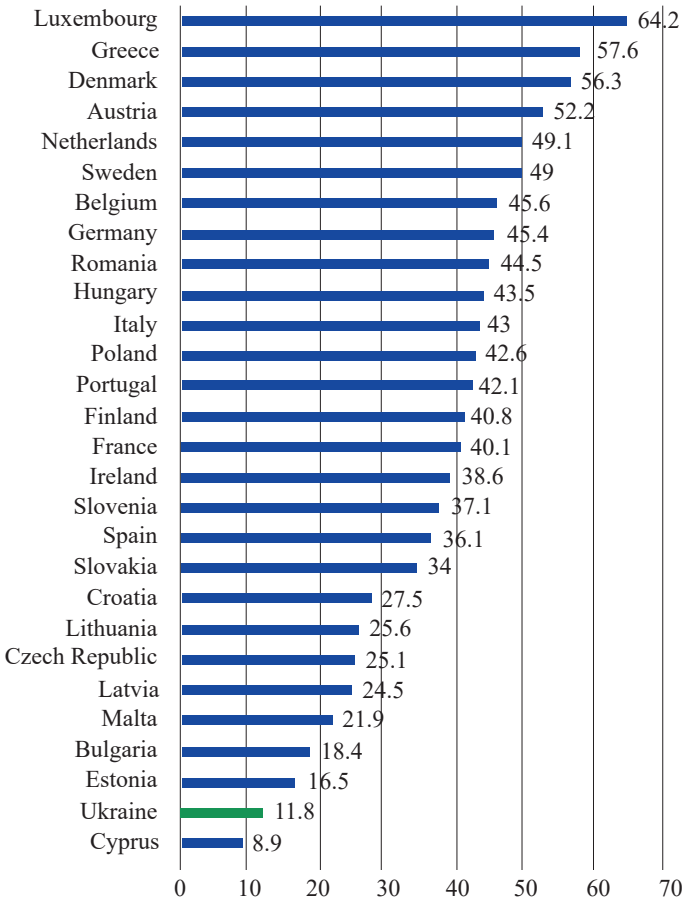

Figure 1*. Total average tax burden on individuals in the EU and Ukraine in 2011-2020, %**

Source: *Eurostat (n.d.), Official website of the Ministry of Finance of Ukraine (n.d.), Official website of the State Statistics Service of Ukraine (n.d.)*

Among the EU countries in the period under study, the top three with the highest tax burden included Luxembourg, Greece, and Denmark, while the outsiders were Bulgaria, Estonia, and Cyprus. Ukrainian households also did not experience a considerable tax burden during the period under study since the country was second only to Cyprus in terms of the level of tax burden on individuals.

In Ukraine, as already noted, to compensate for the underutilisation of the fiscal potential of individuals with high incomes, the tax burden is shifted towards broad layers of wage earners in the official sector of the economy, who have minimal opportunities to evade income tax and military duty. This increases the negative impact of taxation on the growth rate of wages and conditions for investment of the main part of Ukrainian citizens. I. Verkhovod et al. (2020) believe that the only possible way to overcome the problems of shifting the tax burden towards citizens with small and medium-sized labour incomes is to strengthen the differentiation of tax pressure by introducing added differentiation of rates on personal income tax for distinct groups of taxpayers, which should ensure that the factual tax burden is brought into line with the solvency of the population.

Scientists say that the total tax burden does not reflect the real scale of the tax burden of individuals. Thus, T.I.Yefymenko & A.M. Sokolovska (2013) suggest calculating the tax burden on the population, considering the effect of shifting indirect taxes. However, the method of calculating this indicator is perplexing because it does not consider the shift of duty, and to consider the shift of excise tax, consumer spending of the population on excisable products is necessary, which is not provided in the statistics. S.H. Operenko (2018) recommends calculating a separate indicator of the tax burden on the consumption of individuals. However, this indicator cannot be combined with the overall tax burden because it is based on household expenses, not income. A.M. Sokolovska (2006) puts forward a proposal, apart from the tax burden generated by the income effect, to also calculate the tax burden generated by the substitution effect. Moreover, the researcher suggests calculating the latter indicator using the formula of A. Kharberger, most of the parameters of which cannot be quantified due to the need to apply a considerable amount of information and the need to interpret qualitative characteristics into numerical values.

Considering the methodological uncertainty of calculating the tax burden with the effect of shifting, for the purposes of this study, the authors of this paper limited themselves only to the indicator of the total tax burden on individuals.

In the context of assessing the impact of the fiscal mechanism on household investment activity, a correlation-regression analysis was performed. To construct the regression model, two parameters that are considered as key factors influencing household investment (Y) were selected, namely: tax payments paid by the population (X_1), and the total tax burden on individuals (X_2). Correlation-regression analysis was performed based on factual data for 2011-2020 using MS Excel, and its results are presented in Table 5.

***Table 5**. Regression model of the impact of the components of the fiscal mechanism on household investment in the EU and Ukraine in 2011–2020**

Country	Regression equation	Pair correlation coefficient		Student's t-test	
		Between X_1 and Y	Between X_2 and Y	Relationship between X_1 and Y	Relationship between X_2 and Y
Austria	$Y=19527.95+0.34X_1-366.49X_2$	0.881 (s)	-0.56 (m)	5.27 (s)	1.91 (w)
Belgium	$Y=7952.52+0.29X_1-207.03X_2$	0.883 (s)	-0.686 (m)	5.33 (s)	2.66 (w)
Bulgaria	$Y=-2420.99+0.55X_1+58.01X_2$	0.881 (s)	0.745 (s)	5.28 (s)	3.16 (s)
Greece	$Y=17125.08+0.10X_1-266.29X_2$	0.117 (н)	-0.837 (s)	0.33 (w)	4.33 (s)
Denmark	$Y=91319.09+0.33X_1-3264.22X_2$	0.758 (s)	0.115 (н)	3.29 (s)	0.33 (w)
Estonia	$Y=804.46+0.85X_1-61.08X_2$	0.98 (s)	-0.868 (s)	14.02 (s)	4.93 (s)
Spain	$Y=109064.75+0.12X_1-2546.72X_2$	0.0542 (н)	-0.764 (s)	0.15 (s)	3.35 (s)
Ireland	$Y=16229.76-0.02X_1-287.48X_2$	0.846 (s)	-0.971 (s)	4.49 (s)	11.48 (s)
Italy	$Y=238548.93-0.40X_1-813.29X_2$	-0.49 (w)	-0.216 (н)	1.6 (w)	0.63 (w)

Table 5, Continued

Country	Regression equation	Pair correlation coefficient		Student's t-test	
		Between X_1 and Y	Between X_2 and Y	Relationship between X_1 and Y	Relationship between X_2 and Y
Cyprus	$Y=-1343.65+2.42X_1-55.78X_2$	0.965 (s)	0.563 (m)	10.35 (s)	1.93 (w)
Latvia	$Y=79.132+0.41X_1-5.58X_2$	0.94 (s)	-0.75 (s)	7.77 (s)	3.21 (s)
Lithuania	$Y=856.75+0.06X_1+19.25X_2$	0.869 (s)	0.92 (s)	4.97 (s)	6.66 (s)
Luxembourg	$Y=1395.05+0.23X_1-14.60X_2$	0.873 (s)	0.731 (s)	5.07 (s)	3.03 (s)
Malta	$Y=-846.57+0.06X_1+54.38X_2$	0.933 (s)	0.963 (s)	7.33 (s)	10.11 (s)
Netherlands	$Y=-5036.15+0.51X_1-698.83X_2$	0.961 (s)	0.223 (н)	9.81 (s)	0.65 (w)
Germany	$Y=141266.42+0.23X_1-1960.69X_2$	0.954 (s)	-0.103 (н)	9.00 (s)	0.29 (w)
Poland	$Y=69180.41-0.06X_1+570.90X_2$	-0.524 (m)	-0.286 (н)	1.74 (w)	0.84 (w)
Portugal	$Y=6217.99+0.31X_1-196.66X_2$	0.554 (m)	-0.66 (m)	1.88 (w)	2.48 (w)
Romania	$Y=87556.59+0.79X_1-2078.32X_2$	0.888 (s)	0.674 (m)	5.47 (s)	2.58 (w)
Slovakia	$Y=2416.98+0.42X_1-98.16X_2$	0.826 (s)	0.36 (w)	4.15 (s)	1.09 (w)
Slovenia	$Y=-789.64+0.19X_1+24.28X_2$	0.969 (s)	0.716 (s)	11.03 (s)	2.9 (s)
Hungary	$Y=1325599.10+0.51X_1-50679.61X_2$	0.963 (s)	-0.428 (w)	10.14 (s)	1.34 (w)
Ukraine	$Y=215790.08+0.50X_1-20676.37X_2$	0.605 (m)	0.418 (w)	2.15 (w)	1.30 (w)
Finland	$Y=9439.05+0.55X_1-405.36X_2$	0.764 (s)	0.557 (m)	3.35 (s)	1.9 (w)
France	$Y=87643.80+0.30X_1-2012.71X_2$	0.685 (m)	0.554 (m)	2.66 (w)	1.88 (w)
Croatia	$Y=15783.85+0.27X_1-482.63X_2$	0.825 (s)	-0.884 (s)	4.12 (s)	5.34 (s)
Czech Republic	$Y=170227.14+0.39X_1-4875.76X_2$	0.923 (s)	0.655 (m)	6.80 (s)	2.45 (w)
Sweden	$Y=-137695.19+0.25X_1+1320.33X_2$	0.975 (s)	0.643 (m)	12.38 (s)	2.37 (w)

Note: *s – strong connection; m – moderate connection; w – weak connection; l – low connection*
Source: *Eurostat, Official website of the Ministry of Finance of Ukraine, Official website of the State Statistics Service of Ukraine, National Bank of Ukraine*

In the regression equation, the constant evaluates the effect of other factors (not considered in the equation) on the result Y. Coefficients b_1 and b_2 indicate that with an increase in X_1 or X_2 by 1, Y increases (decreases) by a certain number. In most EU countries (except Spain, Italy, and Poland) and in Ukraine, the coefficient b_1 showed that the growth of tax payments paid by citizens leads to an increase in their investment. This is conditioned upon the fact that usually an increase in tax revenues from households is associated with an increase in their income, respectively, the increase in the latter positively affects the scale of investment. In Ukraine, an increase in taxes paid by the population by UAH 1 leads to an increase in their investment by UAH 0.5. In many EU countries (except Bulgaria, Lithuania, Malta, Germany, Poland, Slovenia, and Sweden) and in Ukraine, the coefficient b_2 showed that an increase in the tax burden on individuals leads to a decrease in their investment. This situation is quite logical because an increase in tax pressure on households

is accompanied by a decrease in their income, and therefore their ability to invest. In Ukraine, an increase in the tax burden on individuals by 1% leads to a reduction in their investments by UAH 20,676.71. Furthermore, in many EU countries, the calculated pair correlation coefficients showed a strong or moderate linear relationship between tax payments paid by households and their investment volumes, which is confirmed by statistically significant Student's t-test. However, the calculated pairwise correlation coefficients showed mostly a moderate, weak, or low relationship between the tax burden on households and the scale of their investment, which is confirmed mainly by statistically insignificant Student t-test. Thus, for Ukraine, the statistical insignificance of the student's t-test indicates that neither the volume of tax payments paid by the population nor the total tax burden have a substantial impact on the scale of household investments. The authors of this paper believe that this situation is explained by a considerable shadow sector of the national economy, because of which many household incomes stay tax-free, respectively, and the level of tax burden cannot be correctly calculated and have a direct impact on individual investments.

If the factors are different in nature and/or have different units of measurement, as in the case of the tax burden on individuals (measured as a percentage) and household investments (measured in monetary units), then the bj regression coefficients for distinct factors are incomparable. Therefore, regression equations are supplemented with relative indicators of the connection tightness of factors with the performance indicator, which allow ranking factors according to the strength of influence on the result. Private elasticity coefficients are primarily among such indicators of connection tightness. These coefficients show how many percentages, on average, the characteristic-result Y changes with an increase in the characteristic-factor Xj by 1% from its average level at a fixed state of other factors of the model. In addition, an objective assessment of the close relationship of factors with the effective indicator is given by the determination coefficient. The closer the value of this coefficient is to 1, the more the regression equation explains the behaviour of the resulting Y indicator.

The results of calculations of indicators of the connection tightness between tax payments paid by the population (X_1), and the total tax burden on individuals (X_2) and household investments (Y) are presented in Table 6.

***Table 6**. Indicators of the tight connection of factors (components of the fiscal mechanism) to the result (household investment) in the EU and Ukraine in 2011-2020**

Country	Elasticity coefficients		Determination coefficient
	Effect of X_1 on Y	Effect of X_2 on Y	
Austria	0.978 (m)	-1.076 (c)	0.91 (h)
Belgium	1.064 (c)	-0.404 (m)	0.80 (h)
Czech Republic	0.793 (m)	-0.529 (m)	0.86 (h)
Denmark	2.067 (c)	-2.121 (c)	0.86 (h)
Estonia	1.201 (c)	-0.996 (m)	0.99 (h)
Finland	1.495 (c)	-1.153 (c)	0.66 (mi)
France	0.945 (m)	0.642 (m)	0.51 (mi)
Germany	0.717 (m)	-0.482 (m)	0.97 (h)
Greece	0.621 (m)	-3.248 (c)	0.70 (h)
Hungary	1.701 (c)	-1.755 (c)	0.98 (h)
Ireland	-0.101 (m)	-2.391 (c)	0.94 (h)
Italy	-1.224 (c)	-0.382 (m)	0.26 (w)
Luxembourg	0.808 (m)	-0.394 (m)	0.78 (h)
Latvia	1.068 (c)	-0.162 (m)	0.89 (h)
Lithuania	0.156 (m)	0.308 (m)	0.87 (h)
Netherlands	2.019 (c)	-0.888 (m)	0.93 (h)
Poland	-0.218 (m)	0.317 (m)	0.31 (mi)
Portugal	1.336 (c)	-1.352 (c)	0.92 (h)
Slovakia	1.279 (c)	-1.008 (c)	0.88 (h)
Slovenia	0.926 (m)	0.609 (m)	0.96 (h)
Spain	0.539 (m)	-2.475 (c)	0.63 (mi)
Sweden	1.56 (c)	0.497 (m)	0.96 (h)

Table 6, Continued

Country	Elasticity coefficients		Determination coefficient
	Effect of X_1 on Y	Effect of X_2 on Y	
Ukraine	1.385 (c)	-3.312 (c)	0.46 (mi)
Bulgaria	1.633 (c)	0.499 (m)	0.78 (h)
Romania	1.098 (c)	-1.804 (c)	0.87 (h)
Malta	0.163 (m)	2.907 (c)	0.93 (h)
Cyprus	2.449 (c)	-0.390 (m)	0.93 (h)
Croatia	0.797 (m)	-1.078 (c)	0.86 (h)

Note: *c – considerable impact; m – minor impact; h – high impact; s – substantial impact; mi – moderate impact; w – weak impact*

Source: *Eurostat, Official website of the Ministry of Finance of Ukraine, Official website of the State Statistics Service of Ukraine, National Bank of Ukraine*

As shown in Table 6, in 2011-2020, the private elasticity coefficient for determining the closeness of the relationship between tax payments paid by individuals and their investments in slightly more than half of the EU countries and in Ukraine showed that when the factor X_1 changes to 1%, the performance indicator will change by more than 1%, i.e., its impact is substantial. For Ukraine, a 1% increase in tax payments paid by the population leads to an increase in household investment by 1.393%. Similarly, the private elasticity coefficient for determining the closeness of the connection between the tax burden on individuals and their investments in slightly more than half of the EU countries and in Ukraine testified that when the X_2 factor changes by 1%, the effective indicator changes by more than 1%, i.e., its influence is substantial. For Ukraine, an increase in the tax burden on citizens by 1% leads to a decrease in household investment by 3.258%. It was found that the value of the coefficient of determination for most EU countries is high, i.e., in the situation under study, a considerable percentage of the total variability of Y is explained by changes in factors X_j. For Ukraine, the value of the coefficient of determination is noticeable, accordingly, only 46% of the total change in household investments depends on the influence of the components of the fiscal mechanism, and the rest of the changes are explained by the influence of other factors. According to S. van Parys & S. Kames (2010), such factors are expenses of individuals for compliance with the requirements of tax legislation and investment taxation conditions that ensure a positive attitude of taxpayers towards investment processes. Such factors are difficult to quantify, and therefore they are rarely reflected in regression models. However, institutional stability, trust, and transparency in the tax system should not be forgotten because they play an essential role in taxpayers' investment decisions.

Correlation-regression analysis has shown that the components of the fiscal mechanism affect household investment in most EU countries. In Ukraine, such an impact is also observed, but it is insignificant and negative in terms of the tax burden.

To offset the negative impact of taxes on individual investments, many EU countries and Ukraine are introducing diverse benefits that stimulate household investment activity. These benefits were divided into several groups as follows:

1. Deduction of interest on mortgage loans for the purchase of own housing from the object of PIT taxation. This benefit is introduced in Belgium (only for regional PIT), Bulgaria, Estonia, Italy, the Netherlands, Germany, Portugal, and the Czech Republic (PricewaterhouseCoopers International Limited, 2022). This benefit also applies in Ukraine because according to Article 166 of the Tax Code of Ukraine, a taxpayer shall have the right to include in the tax discount in the reduction of the taxpayer's taxable income based on the results of the reporting tax year a part of the amount of interest paid by such a taxpayer for using a housing mortgage loan (Tax Code of Ukraine, 2010). However, as shown by the research of L.M. Akimova et al. (2018), the granting of a tax discount does not have a special effect on the population's investment in real estate since such investments are mostly influenced by monetary factors, namely the depreciation of the national currency.

2. Deduction of expenses for the construction (acquisition) of a new house/apartment or renovation of one's own home from the object of PIT taxation. This benefit is valid in Austria, Bulgaria (only in relation to the costs of improvement (repair) of housing), Poland (only in relation to the costs of reconstruction (renovation) of dwellings of historical value) (PricewaterhouseCoopers International Limited, 2022). In Ukraine, such a tax benefit is not provided.

3. Deduction of costs for energy- and heat-efficient modernisation of housing from the object of PIT taxation. This benefit is used in Spain, Poland, Finland, France (PricewaterhouseCoopers International Limited, 2022). In Ukraine, such a tax benefit has not been introduced.

4. Deduction of expenses for the purchase of shares of newly established or operating, usually innovative, small and medium-sized enterprises from the object of PIT taxation. This benefit has become widespread

in Belgium, Cyprus, Greece, and Spain (PricewaterhouseCoopers International Limited, 2022). There is no such tax benefit in Ukraine.

5. Deduction of other investment-oriented expenses from the object of PIT taxation. Thus, in Cyprus, individuals who invest in audio-visual infrastructure and technological equipment related to audio-visual infrastructure are entitled to a 20% deduction from the personal income tax object of the cost of such investments if certain criteria and conditions are met. Ireland has personal income tax breaks aimed at stimulating employment and investment (EII), start-up relief for entrepreneurs (SURE), and start-up capital incentives (SCI). EII benefits are provided for making investments in certain types of activities and allow an individual to deduct up to EUR 250,000 per year from the object of personal income tax in each tax period (EUR 500,000 for those who invest for a minimum seven-year period). Benefits like SURE are aimed at citizens who leave their jobs to start their own business. The maximum tax benefit that can be qualified as SURE is a deduction of EUR 700,000 from the object of personal income tax (EUR 100,000 per year for the previous six tax years and EUR 100,000 in the current year). Benefits such as SCI were introduced for 2019-2021 and are aimed at microenterprises at an early stage, SCI aims to mitigate the special conditions for microenterprises at an early stage of raising capital to start a business. Moreover, a microenterprise is considered a business entity with less than 10 employees, whose turnover and/or balance sheet is less than EUR 2 million. The lifetime deduction from the object of personal income tax is EUR 500,000 (PricewaterhouseCoopers International Limited, 2022).

Thus, some EU countries have introduced tax and investment benefits for individuals. However, according to A. Celani et al. (2022), the introduction of tax incentives to encourage investment in developed countries is usually not accompanied by an assessment of their effectiveness, and therefore it is impossible to confidently discuss their positive effect on maximising household investment. Therefore, tax incentives for individuals to increase their investment activity are not widely used both in the EU countries and in Ukraine.

CONCLUSIONS

The fiscal mechanism can regulate the investment activity of households in terms of its individual components, namely taxes. The number and amount of taxes, as well as the tax burden on individuals, not only affect the financial ability of individuals to make investments, but also the desire of citizens to make investment decisions under certain tax conditions.

In the EU countries, households pay many taxes, namely taxes on income and capital gains, social tax payments, property, and other taxes that have an environmental, administrative, and tourist designation. In Ukraine, individuals pay less taxes, they are not subject to a single social contribution, part of property, environmental, and other tax payments. Accordingly, the total tax burden on the population in the most developed EU countries is much higher than in Ukraine. Notably, in the EU countries, the tax burden is evenly borne by all households because rates on personal income tax are mostly progressive or low-progressive. In Ukraine, the total tax burden is borne by citizens with low and middle income who work in the official sector of the economy because the rate on personal income tax is proportional.

The correlation-regression analysis showed that in most EU countries (except Spain, Italy, and Poland) and in Ukraine, the growth of taxes paid by households causes an increase in their investment, since it indicates an improvement in the financial and property condition of the population and an expansion of investment opportunities. In many EU countries (except Bulgaria, Lithuania, Malta, Germany, Poland, Slovenia, and Sweden) and in Ukraine, an increase in the overall tax burden on individuals leads to a decrease in their investment since it describes a reduction in the financial resources of citizens and a decrease in the ability to invest. Therefore, the prospects for further scientific research are to find ways to mitigate the negative impact of taxes as a key component of the fiscal mechanism on household investments in Ukraine, for which it is necessary to investigate and use the practices of EU countries regarding the implementation of various tax benefits that stimulate the investment activity of individuals.

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Роль фіскального механізму у регулюванні інвестиційної активності домогосподарств в країнах ЄС і в Україні

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Анотація. Фіскальний механізм, який слугує засобом реалізації фіскальної політики, завдяки організації фіскальних відносин шляхом зміни механізмів формування надходжень і витрат бюджету, спрямовує встановлені фіскальні взаємозв'язки, управляє каналами проходження та напрямами фіскальних потоків, уточнює пропорції розподілу фінансових ресурсів і, таким чином, забезпечує регулювання інвестиційної активності домогосподарств. Для України в контексті її євроінтеграційних прагнень дослідження впливу складових фіскального механізму, зокрема податків, на здійснення інвестицій населення у країнах ЄС набуває особливої актуальності. Тому метою статті є формування цілісного уявлення про елементи фіскального механізму, які обумовлюють зміни в інвестиційних процесах на мікрорівні в країнах ЄС і в Україні, а також проведення кореляційно-регресійного аналізу для виявлення кількісного впливу фіскального механізму на інвестиційну активність домогосподарств. У ході дослідження розглянуто українську та європейську практику оподаткування населення та здійснено розрахунок загального податкового навантаження на фізичних осіб в країнах ЄС і в Україні. Проведено кореляційно-регресійний аналіз впливу елементів фіскального механізму на інвестиції домогосподарств у країнах ЄС і в Україні, який засвідчив, що найбільший вплив на здійснення інвестицій громадян чинили масштаби їх оподаткування, тоді як загальне податкове навантаження виконувало другорядну роль у регулюванні інвестиційних процесів на мікрорівні. У результаті дослідження доведено, що в Україні для підвищення інвестиційної активності домогосподарств необхідно враховувати досвід країн ЄС та вдосконалювати ті елементи фіскального механізму, які мають найбільший регулювальний вплив на інвестиції. Такою складовою фіскального механізму виступають податки, особливо в частині ефективного надання податкових пільг

Ключові слова: бюджет, податки, інвестування, фізична особа, податкове навантаження

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Attracting Foreign Investment in Cyclic Imbalances of the Economy

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Abstract. Foreign investment is an important economic resource for many countries including Ukraine. The relevance of this study lies in the need to solve problems of attracting foreign investment. The purpose of this study was to consider the conditions for attracting foreign investment in the cyclic imbalances of the world economy. Using the method of correlation-regression analysis, the impact of indicators of financial imbalances was found both in general and by individual sub-indices. The study found the financial imbalances (fiscal, monetary, exchange rate, debt, trade, households, investment, and savings), both present and potential, in the face of the threat of financial and economic crisis. The procedure for assessing financial imbalances in economic activity of the world and their regional groups that implement the process of investment-oriented development was defined. To assess their impact on the volume of foreign direct investment, a comprehensive method of calculating sub-indicators of financial imbalances was proposed, which on the set of certain parameters forms an integrated index of financial imbalances. Methodological approaches to determining the restrictive procedures for the accumulation of financial imbalances associated with the transition of the financial system to a state of financial danger, considering the budget, currency, monetary and debt components were substantiated. The complex method of calculating sub-indicators of financial imbalances in the economy involves the identification of economic risks at the initial stages using the Alert Mechanism on the violation of the balance of the financial and economic systems of the participating countries. Priority areas (real estate and professional services) for attracting foreign investment from around the world were identified. The geostrategic matrix of attraction of foreign investments by the countries of the world was offered

Keywords: financial and economic crisis, budget, currency, redistribution, reforms

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INTRODUCTION

The growth of foreign investment and the existence of hypotheses about their role in the successful transformation of transition economies into market ones, the presence of the fact that they can solve almost all economic problems to obtain additional resources in times of crisis are important sources of funding (Akimov *et al.,* 2020; Banday *et al.,* 2021; Bondarenko *et al.,* 2020). It is critical to attract foreign investment as an effective mechanism to ensure the activities of Ukrainian enterprises, creating the possibility of technological modernisation of market infrastructure in all areas of economic process (Nagachevska *et al.,* 2020; Kossak & Yanovytska, 2020; Reznik *et al.,* 2019). Scientists consider the problem of attracting foreign investment by proposing correspdonding regulatory mechanisms (Komarnytska *et al.,* 2020; Kulish *et al.,* 2018; Peres *et al.,* 2018).

Theoretical and practical studies of the unevenness of the economy and the different dynamics of economic progress of countries and regions, are covered in many works (Shapiro *et al.,* 2018; Economou, 2019; Koziuk, 2018). N.P. Reznik et al. (2019) investigated the specifics of financial relations between rich and poor countries, having conducted a study of international relations from the 1980s to the early 2000s. The results of this paper showed that financial integration has a negative impact on countries with a poorly developed financial system. A.F. Bondarenko et al. (Bondarenko *et al.,* 2020) comprehensively explained the U.S. current account deficit. Attention was paid to the possibilities and impossibilities of resolving these issues for the U.S. The idea was proven that increasing macroeconomic stability requires not just efforts from states but also time resources and cannot be improved at once. Y. Komarynska et al. (2020) dedicated their studies to the problem of imbalances in the economy at various scales concentrating on global imbalances and described the features of an open economy (inclusion in international economic relations and in the global trend of development, freedom of access to the outside world of economic subjects of the country; foreign economic barriers; convertibility of the national currency) in this context. V. Kossak & H. Yanovytska (2020) investigated theoretical issues related to foreign investment and considered the theoretical foundations of the available models and their implementation in Japan and the United States. The researchers established the compatibility of the social and private interests of direct foreign investment. O. Chygryn et al. (2018) attempted to determine whether the saving glut hypothesis is correct. The researchers built a model where the US receives exogenous capital inflows which are calibrated to match the current account deficits.

The studies of many scientists concern the aspect of managing financial imbalances through the mechanism of attracting foreign investment and attracting foreign investment (Amosha *et al.,* 2018; Melnyk & Kasianok, 2017; Ganic & Hrnjic, 2019). A. Kulish et al. (2018) investigated the phenomenon of inflation and ways to combat it to ensure financial stability. They concluded that for this purpose, it is important to develop a policy in advance, predicting possible processes in the country's economy. O. Boiko et al. (2020) devoted their research to the problem of global external imbalances. Having considered this issue on the example of several countries, they concluded that to overcome it, each country should implement its own specific policy – targeted policy. K. Muço et al. (2018), L. Wang et al. (2022) paid considerable attention to the issue of account balances in different countries at the macrolevel of the economy, the causes of uncertainty in developing countries. The issues of the currency crisis were revealed in the research by X. Xu et al. (2019). Scientists have identified indicators (banking crisis, domestic credit, rate, imports, output, deposits, exports, international reserves), that would help predict the emergence of a crisis at the beginning of the process which would make it possible to take the necessary measures in time.

The purpose of this study was to justify the ambivalent relationship between financial imbalances and foreign direct investment flows, which are based on monitoring the dynamics of indicators of potentially dangerous determinants allows quantitative forecasting of their consequences and allows developing measures to support investment-oriented economic development.

MATERIALS AND METHODS

The reasons for financial imbalances differ in each country. Thus, there is uncertainty that indicators of financial imbalances calculated for some countries are acceptable for assessing the crisis in other countries. Thus, for the assessment of indicators of financial imbalances in the G-20 (The Group of Twenty) states, a scheme has been agreed, which includes two stages (Pehkova, 2018). The first stage of the assessment is to identify "problematic" countries in which the economic situation is the cause of the emergence and maintenance for a long time of significant systemic imbalances. The results of the presented system of monitoring the financial condition of the G-20 states allowed to determine that to assess financial imbalances it is necessary to identify seven systemic economies, namely: China (high private sector savings and current account surplus); France (considerable current account deficit and growing government debt), Germany (high government debt and significant current account surplus), India (budget deficit), Japan (considerable public debt), USA (significant budget deficit combined with current account deficit), Great Britain (low level of private sector savings at the same time with high level of public debt) (Färe *et al.,* 2018).

The second stage of the assessment involves an in-depth analysis of the opportunities for sustainable and balanced growth of the countries selected in the

first stage. For this purpose, the forecast probability of economic development of the countries is carried out. There are requirements for the development of financial imbalances (indicators should not exceed regulatory values) for G-20 states that produce 5% of the total GDP of the countries of this group. Such countries are classified as high-level, because there is a significant degree of risk of threatening imbalance, so the economy of these countries negatively affects the rest of the world (Pehkova, 2018). This approach allows considering the greatest potential of influence of large economies. Notably, the structure of European economic regulation is aimed at identifying imbalances in the G-20, and it is based on the Macroeconomic Imbalance Procedure (MIP) (2021), which includes two stages. The first stage involves identifying economic risks at the early stages of their occurrence using the Alert Mechanism, about violations of the balance of financial and economic systems of the participating countries. The second stage deepens the study of the economic state of selected risk countries and their vulnerability assessment; provides relevant proposals for improving macroeconomic policy. The procedure for determining macroeconomic imbalances in the G-20 and identifying internal and foreign economic asymmetry of investment-oriented development allows developing recommendations for making changes to the national policy to overcome them (Peres *et al.*, 2018; European Commission, 2021). The notification mechanism includes indicators of financial imbalances (with threshold values of their changes), which are presented in Table 1.

***Table 1**. Threshold values of indicators of financial imbalances according to the EU methodology*

Indicator	Calculation algorithm	Threshold value	
		For euro area countries	For non-euro area countries
Current account balance relative to GDP (average for 3 years), in % of GDP	$\left(\frac{CA}{GDP}\right)_t + \left(\frac{CA}{GDP}\right)_{t-1} + \left(\frac{CA}{GDP}\right)_{t-2} - 100,$ where *CA* is the current account balance; *GDP* is the GDP volume	from -4 to +6%	from -4 to +6%
Net international investment position, in % of GDP	$\frac{NIIP_t}{GDP_t} \times 100,$ where *NIIP* is the net international investment position; *GDP* is the GDP volume	-15%	-35%
Market share of the country's exports, % change in 5 years	$\frac{\left(\frac{EXPc}{EXPworld}\right)_t - \left(\frac{EXPc}{EXPworld}\right)_{t-5}}{\left(\frac{EXPc}{EXPworld}\right)_{t-5}} \times 100,$ where *EXPc* is the volume of exports of the country under study; *EXPworld* are the global exports	-6%	-6%
Index of the nominal value of a unit of labour, % change over 3 years	$\frac{(ULC)_t + (ULC)_{t-3}}{(ULC)_{t-3}} \times 100,$ where *ULC* is the nominal labour costs per unit cost	+9%	+12%
Real effective exchange rate, % change in 3 years	$\frac{(REEP\_HICP\_35)_t - (REEP\_HICP\_35)_{t-3}}{(REEP\_HICP\_35)_{t-3}} \times 100,$ where *REEP_HICP_35* is the real effective exchange rate with HICP deflator based on 35 trading partners; *HICP* is the harmonised consumer price index	from -5 to +5%	from -11 to +11%
Consolidated private sector debt, in % of GDP	$\frac{PSD_t}{GDP_t} \times 100,$ where *PSD* is the amount of private sector debt; *GDP* is the GDP volume	160%	160%
Loan to the private sector, in % of GDP	$\frac{PSCF_t}{GDP_t} \times 100,$ where *PSCF* is the amount of loans granted to the private sector; *GDP* is the GDP volume	15%	15%
Real estate price index, % change over the year	$\left(\frac{\frac{HPI_t}{DEFL} - \frac{HPI_{t-1}}{DEFL_{t-1}}}{\frac{HPI_{t-1}}{DEFL_{t-1}}}\right) \times 100,$ where *HPI* is the residential real estate price index; *DEFL* is the GDP deflator	6%	6%

Table 1, Continued

Indicator	Calculation algorithm	Threshold value	
		For euro area countries	For non-euro area countries
Debt of the general government sector, in % of GDP	$\frac{GGD_t}{GDP_t} \times 100$, where *GGD* is the amount of debt of the general government sector; *GDP* is the GDP volume	60%	60%
Unemployment rate (average for 3 years)	$\frac{(UR)_t + (UR)_{t-1} + (UR)_{t-2}}{3} \times 100$, where *UR* is the unemployment rate	10%	10%
Total liabilities of the financial sector, in % of GDP	$\frac{GFD_t}{GDP_t} \times 100$, where *GFD* is the amount of total liabilities of the financial sector; *GDP* is the GDP volume	16.5%	16.5%

***Source**: generated by the authors according to data (Peres et al., 2018; European Commission, 2021; Diachenko et al., 2018)*

Since the accumulation of financial imbalances is often associated with the transition of the financial system to a state of financial danger, the quintessence of methodological approaches to assessing financial imbalances can be considered the Methodology No. 1277 (Order of Ministry..., 2013), according to which financial security contains the following components: budget, currency, monetary, debt security (Fig. 1).

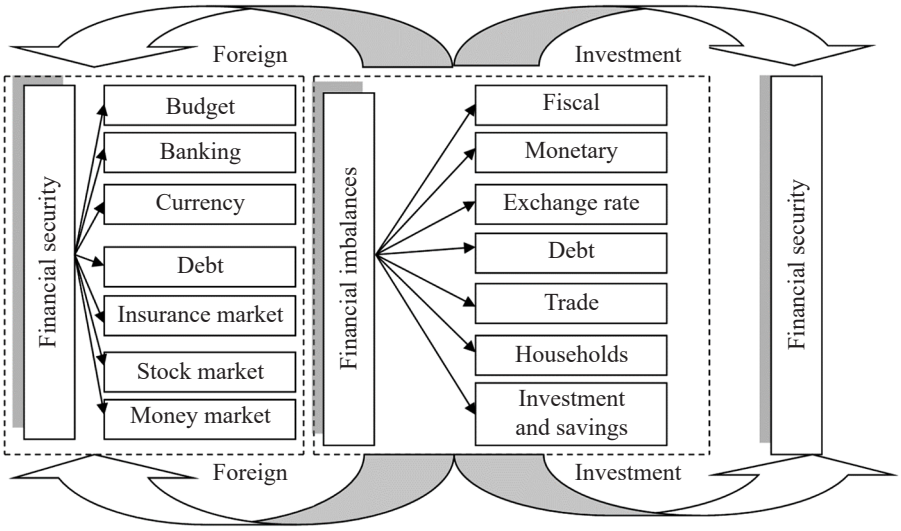

***Figure 1**. Structural and logical scheme of the relationship between financial imbalances, financial security, and foreign investment*

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

Based on the aggregate results of empirical research obtained by the experts of the G-20 states, as well as the conglomeration of scientific developments (Xu *et al.*, 2019), the methodological sequence of creating models for selecting indicators of dangerous financial imbalances was determined. The authors of this research consider it expedient to calculate sub-indicators that characterise the state of imbalances in the distribution of investment resources in the financial market, the needs of the financial system and foreign investment. Among the many indicators of budget formation and use, the following ones are selected: the share of revenues and expenditures in the structure of GDP, as well as the share of revenues from taxes and fees in GDP to determine the degree of diversification of sources of financing public expenditures. The active participants in the financial system are households, which are consumers of goods and services and through savings, form the basis of financial resources for investment. To assess the imbalances in household finances, the following indicators were used: Gini coefficient, the ratio of gross savings to GDP of the country. Other indicators that will characterise the state of the financial system are labour market indicators (they reflect the factors

of the population's propensity to savings, which determines the amount of available domestic investment).

The degree of influence of the stock market on the financial system, in authors' opinion, can be best described by the following indicators: the ratio of market capitalisation and market liquidity to GDP, trading turnover; the number of local companies that have passed the listing procedure. Due to limited market mechanisms and constant state intervention in the financial system, the need for foreign resources is increasing due to inefficient use of national savings and imperfect mechanism for their transformation into investment. Therefore, it is important to estimate the external debt per capita; the ratio of debt service payments to revenues from exports to state budget revenues; separately the authors propose to investigate the attitude of the state towards the policy of international financial institutions. To consider institutional factors, the list of sub-indicators of financial imbalances should be supplemented with indicators of quality of state institutions, which include index of business freedom. In addition, the authors propose to supplement the study of financial institutions with an index of monetary autonomy, according to the following method (Bansal & Thenmozhi, 2020). This index determines the degree of correlation of interest rates in a country with interest rates of one of the reserve currencies depending on the participation of such a country in a currency block, as well as the index of exchange rate flexibility (measures the actual volatility of the country's exchange rate) and financial openness index – a normalised version of the Chinn-Ito index (Koziuk, 2018). The generalised list of the offered sub-indicators of financial imbalances on constituent elements of financial system and character of their influence on financial imbalances in economy (Table 2). The sub-indices of financial imbalances are calculated using the arithmetic mean for each element of the financial system studied, assuming the weight of the indicators at one level.

***Table 2**. Indicators for calculating the integrated index of financial imbalances in the economy*

Imbalances	Indicators and method of calculation	Directions of influence on financial imbalances
Fiscal	State budget balance, % of GDP	Stimulant
	Share of state budget expenditures in GDP, % of GDP	Stimulant
	Share of taxes, % of GDP	Stimulant
	Ratio of budget revenues to GDP, % of GDP	Destimulating
Monetary	Inflation rate, % (to the group of the previous period)	Stimulant
	Real interest rate, %	Stimulant
	Money supply, % of GDP	Stimulant
	Domestic loans to the private sector, % of GDP	Stimulant
Currency	Real effective exchange rate	Stimulant
	Gross international reserves, months of imports	Destimulating
	Current account balance of a private bank, % of GDP	Double
	Net international investment position, % of GDP	Double
Household finances	The ratio of the number of persons under 15 and over 65 to the working age population	Stimulant
	The share of the working age population, % of the total population	Destimulating
	Unemployment rate, % of people of working age (15-64 years)	Stimulant
	Gini coefficient	Stimulant
	Gross savings, in% of GDP	Double
	The share of people living on 3.5 dollars. per day, in% of the total population	Stimulant
	Migration balance, % of population	Stimulant
Stock market	Market capitalisation, in% of GDP	Destimulating
	Market liquidity, value of shares to GDP, %	Destimulating
	Trading turnover (ratio of total value to market capitalisation)	Destimulating

Table 2, Continued

Imbalances	Indicators and method of calculation	Directions of influence on financial imbalances
Debt	Total public debt, in% of GDP	Stimulant
	Total external debt, in% of GDP	Stimulant
	The level of external state and state-guaranteed debt per capita, USD	Stimulant
	External debt service payments, in% to annual exports of goods and services	Stimulant
	Interest payments on public debt service, in% to state budget revenues	Stimulant
	Debt to the IMF, in% to GDP	Stimulant
Institutional	Global Competitiveness Index	Destimulating
	Index of freedom of doing business	Destimulating
	Index of monetary autonomy	Destimulating

***Source**: developed by the authors according to data (Koziuk, 2018; Bansal & Thenmozhi, 2020)*

Accordingly, based on sub-indices, the integrated index of financial imbalances is calculated according to formula (1) (Koziuk, 2018; Bansal & Thenmozhi, 2020):

$$I_{fimb} = \frac{k_1 + k_2 + \ldots + k_n}{n} \quad (1)$$

where I_{fimb} is the integrated index of financial imbalances in the economy; $k_1, k_{2,\ldots k_n}$ are the sub-indices of financial imbalances; *n* is the number of sub-indices.

Since the value of the integrated index of financial imbalances in the economy of each country is different, it must be reduced to a normal scale from 0 to 1, using the concept of quartiles, which carries out the gradation of the variation series of the integrated indicator on four quartiles:

0-0.25 – low (safe level of imbalances);

0.25-0.50 – moderate level of financial imbalances;

0.50-0.75 – high (dangerous) level of financial imbalances;

0.76-1.00 – a critical level of financial imbalances.

Thus, the definition of an integrated index of financial imbalances in the world economy becomes possible, considering regional characteristics and their impact on foreign direct investment. The influence of indicators of financial imbalances both as a whole and by individual sub-indices can be determined by correlation-regression analysis. Identification of the relationship and the degree of impact of financial imbalances on the volume of foreign direct investment will be the basis for identifying points of influence on the financial system, the potential measures of state regulation, and for developing a vector of economic mechanism for attracting foreign direct investment.

RESULTS AND DISCUSSION

In 2020, the total inflow of foreign investment decreased by17% to 1.52 trillion USD, which was caused by 27% falling foreign investment flows in developed countries (mainly in the UK and USA) (European Commission, 2021). During 2019, the capital expenditures 5 of thousands of the largest TNCs continued to decline after the beginning of the recession in 2018 (Fig. 2).

The flows of foreign investment in developed countries increased almost 2.0 times in 2018 and in 2019 reached 1.0 trillion USD. Foreign investment increased to 765 billion USD (Fig. 3).

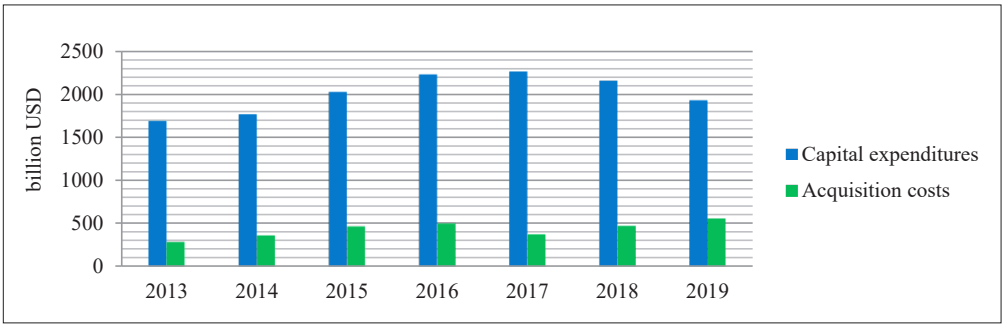

***Figure 2**. Capital expenditures and acquisition costs of the 5,000 largest TNCs for 2013-2019, billion USD*

***Source**: calculated by the authors according to data (UNCTAD, 2013; 2017; 2019)*

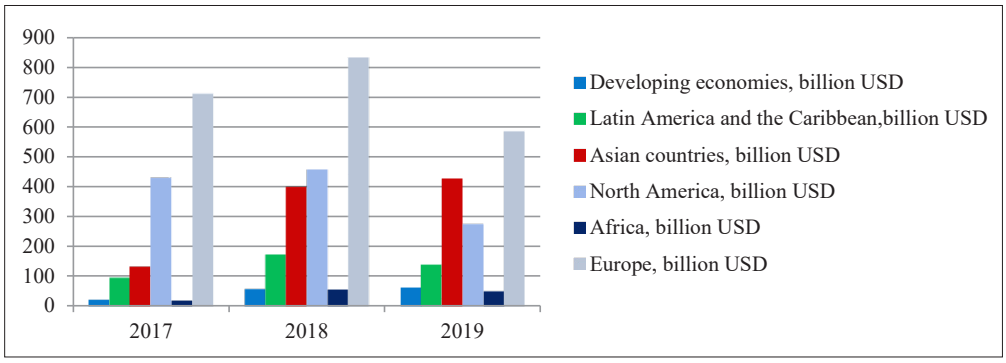

***Figure 3**. Dynamics of inflow of foreign investments by regions of the world, billion USD*
***Source**: calculated by the authors according to data (UNCTAD, 2013; 2017; 2019)*

Analysis of the asymmetry in the distribution of foreign investment in North America and Europe showed an increase in their volume during 2017 and a sharp decline in 2019. In North America, in 2017, foreign investment increased 2.6 times (429.6 billion USD), which was caused by an increase in the inflow of investment to the United States (more than 3.5 times), but in 2019 their volume decreased to 275.5 billion USD, compared to 456.4 billion USD investment in 2018. The most attractive industry for attracting foreign investment in countries is information communications and technology in Asia, Latin America, and the Caribbean (Fig. 3). For developed countries, the priority area for attracting foreign investment is the field of professional services and computer electronics (Fig. 4).

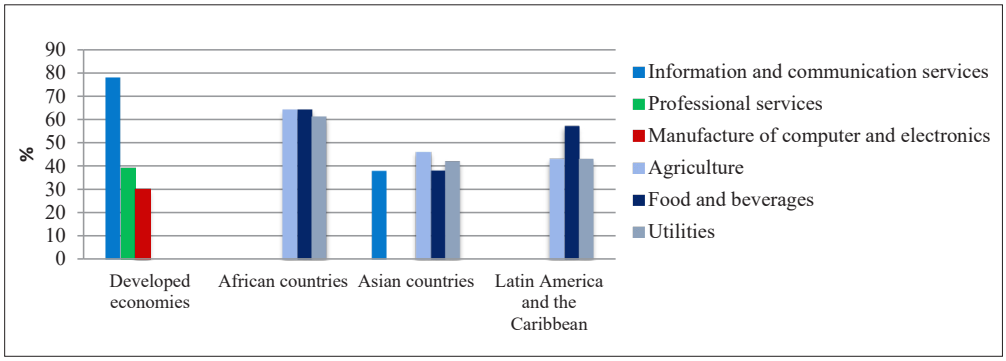

***Figure 4**. The most priority areas of foreign investments in the world, %*
***Source**: calculated by the authors according to data (UNCTAD, 2013; 2017; 2019)*

For Asian countries with different economic systems, the primary spheres of development are agriculture, utilities, food production, and information and communication industry which is a component of specialisation of this complex region in global production networks. In modern conditions, Ukraine, like most countries in a strong development cycle, is unfortunately unable to ensure stable socio-economic development due to available financial resources and needs to attract foreign capital. In 2019, only 300 million USD were attracted to the economy of Ukraine (which is 0.2% of GDP). For comparison, in 2019 this figure for the United States was equal to 31.13% of GDP, Poland – 44.9%, Greece – 9.1% (UNCTAD, 2019). The geographical structure of foreign direct investment attracted to the economy of Ukraine in 2019 was dominated by investments of companies registered in Cyprus (Fig. 5). In 2018, their share was 28.3%, but in 2019 it decreased to 25.7%. Cyprus, the Virgin Islands, Belize – three "classic" offshores – in 2019 in general invested 31.8% foreign investment and 34.6% in 2018.

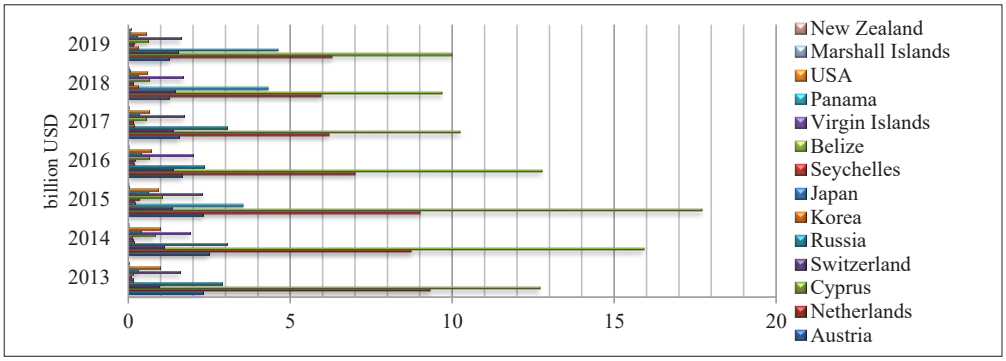

***Figure 5**. Foreign direct investment from around the world in the economy of Ukraine for 2013-2019, billion USD*
***Source**: calculated by the authors according to data (UNCTAD, 2013; 2017; 2019)*

Most offshore investments in Ukraine are Ukrainian or Russian capital, the owners of which use companies in Cyprus and other offshore jurisdictions to optimise taxation and obtain special legal status. According to a study on investment policy (Boiko et al., 2020), the real amount of Russian capital in Ukraine in 2019 was three times higher than officially announced (approximately 9.9 billion USD against 4.61 billion USD). Quite a significant amount of foreign investment from the Netherlands in the telecommunications sector of Ukraine (1.8 billion USD) is explained by favourable tax conditions and the conditions of the current offshore system. The dynamics of investment in Ukraine by the type of economic activity is presented in Figure 6.

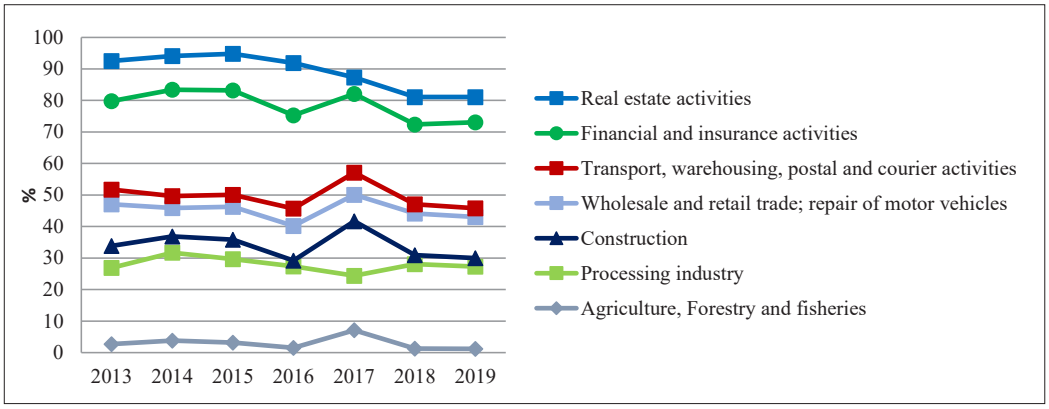

***Figure 6**. The dynamics of investment in Ukraine by the type of economic activity for 2013-2019, %*
***Source**: calculated by the authors according to data (Economy Watch, 2017; International Monetary Fund Official Website, 2017; UNCTAD, 2013; 2017; 2019)*

During 2013-2019, most foreign investments in Ukraine were concentrated in industry (30.6% of direct investments) and in the sphere of financial and insurance activities (27.3% of the total volume of direct investments). Notably, the industry has the highest profitability, and therefore, is the most attractive for foreign investors from Germany (32.6%), Cyprus (27.1%) the Netherlands (30.2%). Despite the presence of foreign investors in Ukraine's economy, unfortunately, the state continues to be among the outsiders of the global investment market, acting mainly as a recipient. As a result of unsystematic government policy to attract foreign investment, there is a situation when foreign capital is distributed among specific sectors of the economy rather unevenly, which leads to disparities in the structure of GDP and creates financial imbalances. The results of regression models of the dependence of value added on foreign investment are presented in Table 3.

***Table 3**. Regression analysis of foreign investment by the type of economic activity in Ukraine*

Types of economic activity	Regression equation	Regression coefficient	Correlation coefficient	Coefficient of determination
Agriculture, forestry, and fisheries	y=136,726.53+401.72x	+401.72	0.818	0.669
Processing industry	y=157,938.75-20.98x	-20.98	0.792	0.627
Construction	y=37,408.71-12.25x	-12.25	0.545	0.297
Trade	y=204,514.70-69.58x	-69.58	0.472	0.223
Transport, warehousing, postal and courier activities	y=99,906.15-85.46x	-85.46	0.468	0.219
Financial and insurance activities	y=60,679.68-2.90x	-2.9	0.390	0.152
Real estate transactions	y=93,352.47-37.28x	-37.28	0.687	0.473

***Source**: calculated by the authors according to data (Economy Watch, 2017; International Monetary Fund Official Website, 2017; UNCTAD, 2013; 2017; 2019)*

Thus, the sphere of financial services, according to calculations, does not contribute to the creation of benefit for the economy (regression coefficient -2.9). This is due to the speculative nature of investment flows; a similar trend is observed for real estate transactions, as there is no positive impact of attracted foreign investment flows on the formation of value added, which causes a negative effect on the regression coefficient (37.3). This means that 1 billion USD involved in these industries causes a deviation of the gross value added by 2.9 and 37.3 dollars in accordance. Negative regression rates were also recorded in almost all types of economic activity, which confirms the expansion of the Ukrainian economy by foreign investors. Therewith, the positive return on gross value added from foreign investment is observed in agriculture. However, increasing the investment attractiveness of this type of economic activity is possible only with the reliable support from the state, especially since the World Trade Organisation does not prohibit such form as subsidising this industry. In the conditions of a catastrophic decline of investment in fixed capital and the aging of fixed assets, the opportunities for further growth of savings are reduced, which, in addition to the inflation is also significantly impacted by inadequate depreciation policy. The problem of qualitative growth of gross and especially net savings is growing, because, in addition to open inflation, in Ukraine there is hidden inflation due to corruption and shady activities, which leads to underestimation of fixed capital by various methods – fictitious bankruptcy, concealment of profits (Melnyk & Kasianok, 2017).

Due to the long-term sectoral structure of imbalance in Ukraine, a divestment model of economic development was created and consolidated, which reduced the competitiveness of Ukrainian producers with the effect of forming a trend of losing their presence in both international and Ukrainian markets. Further preservation of the policy of social populism and the mechanism of pumping out the incomes of non-financial corporations due to inflated lending rates and underfunding for the recovery of fixed assets threatens the country's economy, even with the intensification of world trade. The authors proposed a geostrategic matrix for attracting foreign direct investment (Table 4). Comparison of potential and actual indicators of attracting foreign investment allows assessing the extent to which countries use the available potential to attract foreign investment.

***Table 4**. Geostrategic matrix of attracting foreign investments by countries of the world*

Actual index of attracting foreign investment					
	1st quartile >11% – high	Chad, Liberia	Bahamas, Congo, Jordan, Luxembourg, Mongolia	Bulgaria, Ireland, Israel, Norway	Australia, Belgium, China, Colombia, Kazakhstan, Poland, Saudi Arabia, Singapore, Switzerland, Ukraine, Great Britain,
	2nd quartile 7-11% – average	Armenia, Cambodia, Guinea, Nicaragua, Saint Vincent and the Grenadines, Solomon Islands	Costa Rica, United Republic of Tanzania, Georgia, Honduras, Kyrgyzstan, Libya, Maldives, Malta, Namibia, Seychelles, Sudan	Croatia, Dominican Republic, Egypt, Estonia, Iraq, Portugal, Qatar, Serbia, Tunisia, Uzbekistan	Austria, Canada, Czech Republic, France, Germany, Hungary, India, Indonesia, Mexico, Netherlands, Romania, Spain, Thailand, Turkey, United Arab Emirates, USA
	3rd quartile 1-7% – sufficient	Antigua and Barbuda, Belize, Cape Verde, Central African Republic, Djibouti, Dominica, Fiji, Grenada, Guyana, Mali, Sao Tome and Principe, Vanuatu	Barbados, Botswana, Cameroon, Lao People's Democratic Republic, Mauritius, Moldova, Myanmar, Uganda, Zimbabwe	Algeria, Azerbaijan, Bolivia, Denmark, Gabon, Guatemala, Spain, Jamaica, Latvia, Morocco, Oman, Pakistan, Syria, Trinidad and Tobago	Argentina, Finland, Iran, Italy, Japan, Korea, South Africa, Sweden
	4th quartile <1% – low	Madagascar, Niger	Albania, Equatorial Guinea, Lebanon, Mozambique, Zambia	Ghana, Nigeria, Panama, Turkmenistan, Uruguay	Brazil, Chile, Hong Kong, Malaysia, Peru, Vietnam
		4th quartile (133-178), low	3rd quartile (89-132), sufficient	2nd quartile (45-88), average	1st quartile (1-45), high
	Potential index of attracting foreign investment				
Low				**High**	

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

To divide countries into groups according to the calculated indicators, the concept of quartiles was used and the values of the actual index of foreign investment were obtained, as well as the rating of countries with a potential index of foreign investment was divided into 4 subcategories (low, sufficient, medium, high). Countries that are highlighted in blue are characterised by an excess of the actual index over the potential one, which means that countries that fall into such group are pre-invested, considering the available natural and labour resources, infrastructure, and consumer market. Countries that are highlighted in green are underinvested because the existing conditions for attracting foreign investment (potential index) outweigh the actual ones. Thus, provided that the first (pre-invested) countries improve their investment potential and others (underinvested) create the conditions for attracting more foreign direct investment, while international capital flows will become an instrument of equilibrium in the global economy.

In the context of reorientation of foreign direct investment flows and their equalisation between countries in the system of sectoral financial imbalances, as well as to increase the use of capital both within the country and in the world as a whole, the authors propose to build a rating of investment attractiveness for each economic activity according to the index of regulatory restrictions on foreign investment. The index covers restrictions on foreign investment by four types of measures: 1) limiting the share of foreign investment; 2) discriminatory requirements for the selection and approval of investment projects; 3) rules for key persons; 4) other operating restrictions on the activities of foreign enterprises. The overall restriction index is calculated as a weighted average score for each type of regulatory constraint. The index covers 5 sectors of the economy: processing industry, agriculture, production, construction, and services. The results of the calculation of the integrated index of investment attractiveness (regulatory restriction of foreign investment) by the type of economic activity of the world are presented in Table 5.

***Table 5**. Integral index of investment attractiveness (regulatory restriction of foreign investment) by the types of economic activity of the world*

Country	Processing industry	Agriculture	Production	Construction	Services
Albania	2.14	1.64	0.88	1.33	1.62
Armenia	3.12	2.19	1.32	3.68	2.27
Austria	0.55	0.71	2.19	1.92	0.57
Azerbaijan	1.99	7.31	1.05	1.79	0.62
Belarus	1.47	1.05	2.70	4.54	3.75
Belgium	0.43	0.58	1.97	1.27	0.77
Bosnia and Herzegovina	2.59	2.94	2.13	3.33	3.96
Brunei Darussalam	0.74	14.38	1.37	1.55	4.27
Bulgaria	1.58	1.66	2.33	2.82	3.52
Cayman Islands	0.66	0.93	0.53	2.43	0.58
Chile	1.24	3.16	1.23	1.66	2.06
Croatia	1.25	1.21	1.62	2.05	3.29
Cyprus	0.75	1.15	1.32	2.05	1.63
Czech Republic	1.03	1.24	2.46	2.13	0.85
Denmark	1.03	0.89	2.07	1.64	0.61
Ecuador	2.68	1.95	1.74	1.53	1.36
Estonia	1.59	1.90	2.21	2.07	2.89
Finland	1.15	0.96	2.06	1.83	1.48
France	0.92	0.66	1.86	1.75	0.70
Germany	0.51	0.70	2.24	1.79	0.66
Greece	1.57	0.86	1.86	1.75	0.67
Hungary	0.88	0.75	2.48	1.68	1.06
Iceland	1.25	0.56	2.01	1.81	0.50
Ireland	0.82	0.79	2.25	1.58	0.58
Israel	0.46	0.04	2.27	0.18	0.59
Italy	0.57	0.61	2.17	1.25	0.91
Japan	0.54	0.60	2.29	1.90	0.04
Kazakhstan	1.82	5.01	1.55	2.67	2.38

Table 5, Continued

Country	Processing industry	Agriculture	Production	Construction	Services
Kenya	2.77	2.66	1.09	1.21	2.02
Kyrgyzstan	3.32	1.07	1.47	1.72	2.61
Latvia	2.17	1.03	1.68	2.74	2.74
Luxembourg	0.97	0.66	1.06	1.69	1.17
Malta	0.73	0.01	1.23	0.15	2.30
Mexico	1.32	1.27	1.92	0.60	0.96
Mongolia	3.02	6.46	1.66	1.90	2.11
Montenegro	2.34	4.25	1.15	2.47	4.24
Mozambique	5.86	1.86	1.06	1.78	1.72
Netherlands	1.52	1.56	1.57	1.37	1.16
Nigeria	3.52	1.76	1.56	1.11	1.32
Pakistan	5.16	1.74	1.80	2.16	1.93
Peru	2.26	2.17	1.98	1.85	2.95
Portugal	0.94	1.90	2.09	1.81	1.60
Romania	1.20	0.05	0.51	0.81	1.87
Serbia	2.07	1.55	2.41	2.73	3.10
Slovakia	0.97	1.05	2.78	3.66	1.98
Slovenia	1.18	0.84	2.86	2.40	2.66
Sri Lanka	2.59	1.53	2.28	1.35	2.58
Palestine	0.93	0.82	1.27	1.11	1.91
Swaziland	1.50	0.60	1.46	1.29	2.17
Switzerland	1.37	0.63	2.10	0.36	1.00
Tanzania	2.22	1.04	1.30	0.77	1.23
Uganda	6.52	1.42	1.32	0.90	1.91
Ukraine	2.45	3.17	1.80	2.75	2.74
USA	1.23	1.32	1.40	1.16	1.36
Zanzibar	2.25	0.94	1.04	1.16	0.33
China	1.67	0.24	1.72	0.99	0.82

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

Paying attention to the main subjects in the investment process, especially the United States, Germany and Japan, the most attractive areas for direct investment are real estate and professional services; the least appropriate is to invest in construction. This situation reflects the long-term innovation policy of these countries. In China, the most profitable area of investment is the hotel and restaurant business. However, the low attractiveness of the manufacturing sector is due to public investment policy, in particular direct restrictions on the access of foreign capital to these sectors of the economy. To identify deviations in the redistribution of foreign investment and financial imbalances in particular, the authors identified tools to stimulate investment activity in the world, which are aimed at maximising their revenues, structural, sectoral and intersectoral changes in the economy with the lowest investment costs (Table 6).

***Table 6**. Forms and tools to stimulate investment activity in the world*

Form	Tools
Financial and credit incentives	Loans; investment guarantees
Tax incentives	Reduction of the tax rate
Stimulation of infrastructure provision	Transport guarantees; energy subsidies; freight benefits
Stimulation of specific investment projects	Targeted funding for research and development
Protectionist measures	Customs tariffs

***Source**: compiled by the authors according to data (Banday et al., 2021)*

As a criterion for the effectiveness of institutional levers to minimise financial imbalances can be considered a steady upward trend in investment in the country, its best distribution between areas of economic activity while supporting the interests of all participants which will further ensure the effectiveness of economic levers. Based on data from the Organisation for Economic Cooperation and Development, United Nations Conference on Trade and Development (2013; 2017; 2019), an empirical study of the priority of attracting foreign investment and overcoming financial imbalances in selected 183 countries – exporters of foreign direct investment and 152 countries – importers for the period 2013-2019 is carried out (Figs. 7-12).

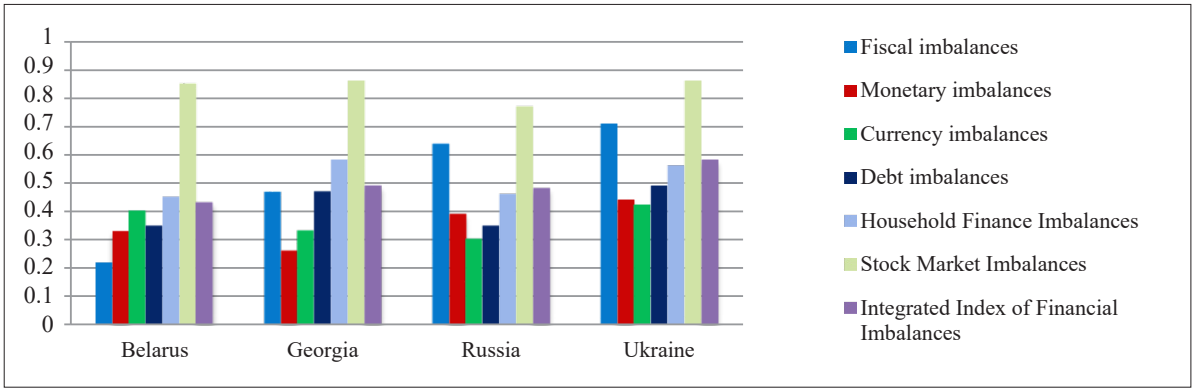

Figure 7. *Integrated index of financial imbalances (I_{fimb}) by regions of Eastern Europe, on average for 2013-2019*
Source: *calculated by the authors based on Organisation of Economic Cooperation and Development; UNCTAD (2013; 2017; 2019)*

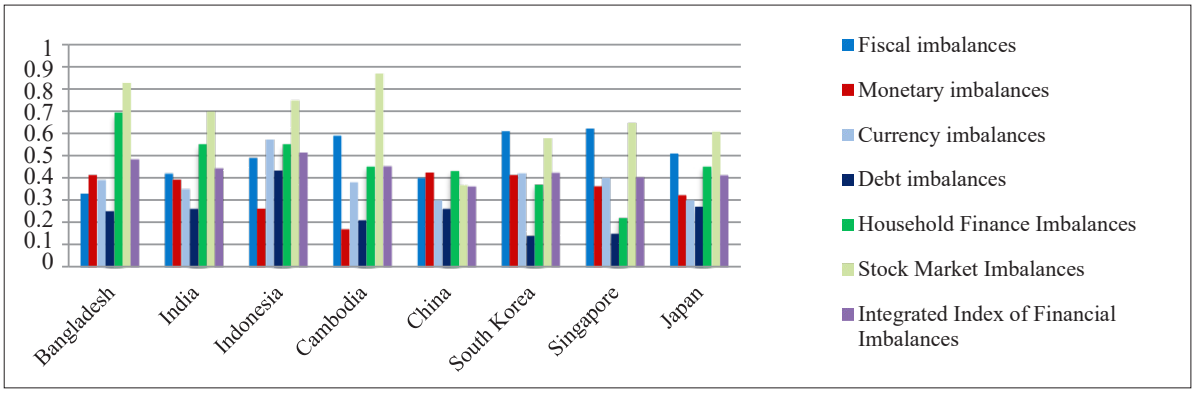

Figure 8. *Integrated index of financial imbalances (I_{fimb}) by regions of Asia, on average for 2013-2019*
Source: *calculated by the authors based on Organisation of Economic Cooperation and Development; UNCTAD (2013; 2017; 2019)*

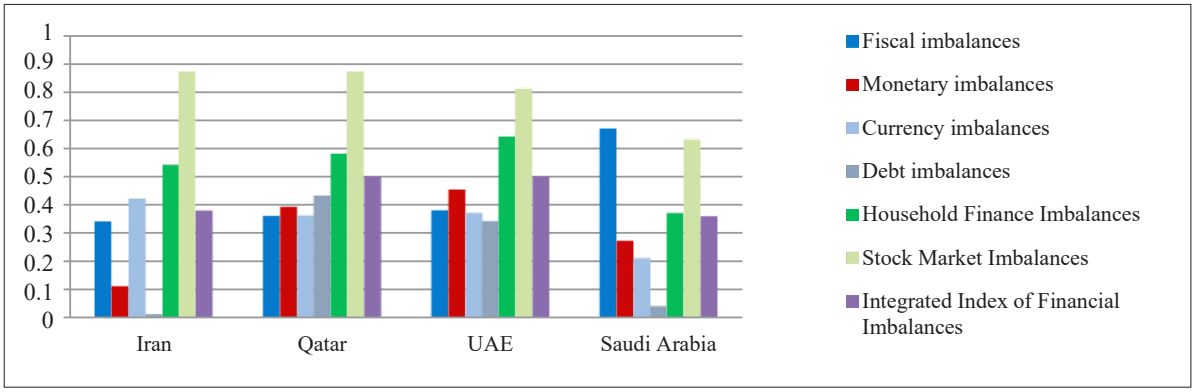

Figure 9. *Integrated index of financial imbalances (I_{fimb}) by regions of the Middle East and the Persian Gulf, on average for 2013-2019*
Source: *calculated by the authors based on [29-31; 33]*

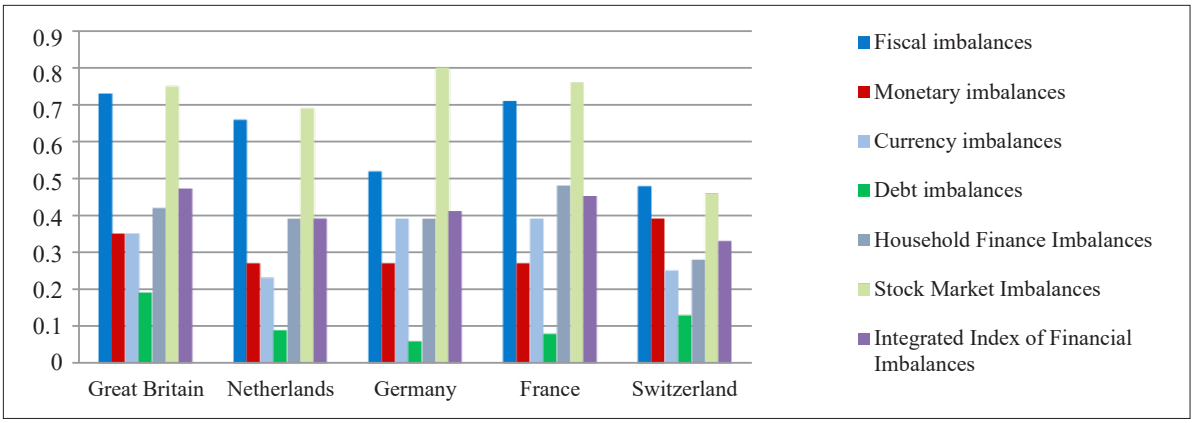

***Figure 10**. Integrated index of financial imbalances (I_{fimb}) by regions of Western Europe, on average for 2013-2019*

***Source**: calculated by the authors based on Organisation of Economic Cooperation and Development; UNCTAD (2013; 2017; 2019)*

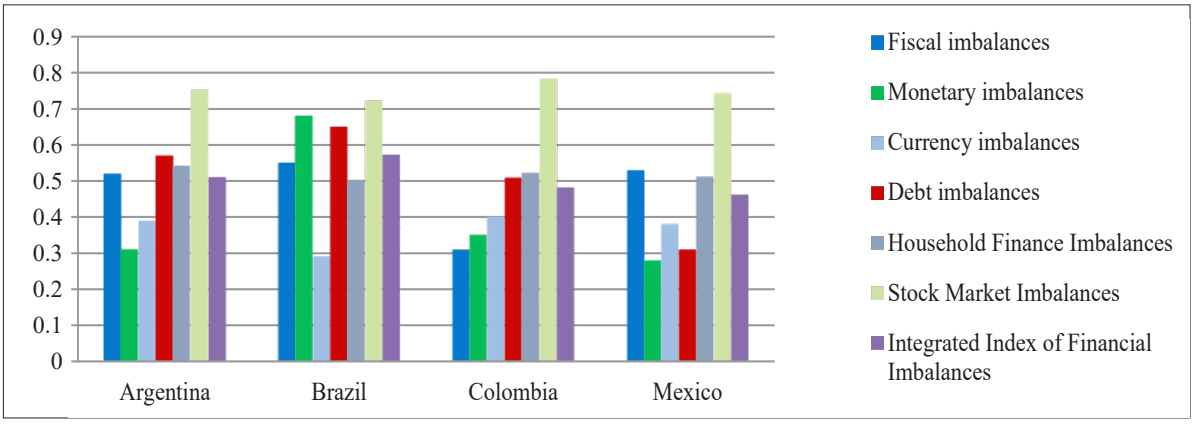

***Figure 11**. Integrated index of financial imbalances (I_{fimb}) by regions of Latin America and the Caribbean, on average for 2013-2019*

***Source**: calculated by the authors based on Organisation of Economic Cooperation and Development; UNCTAD (2013; 2017; 2019)*

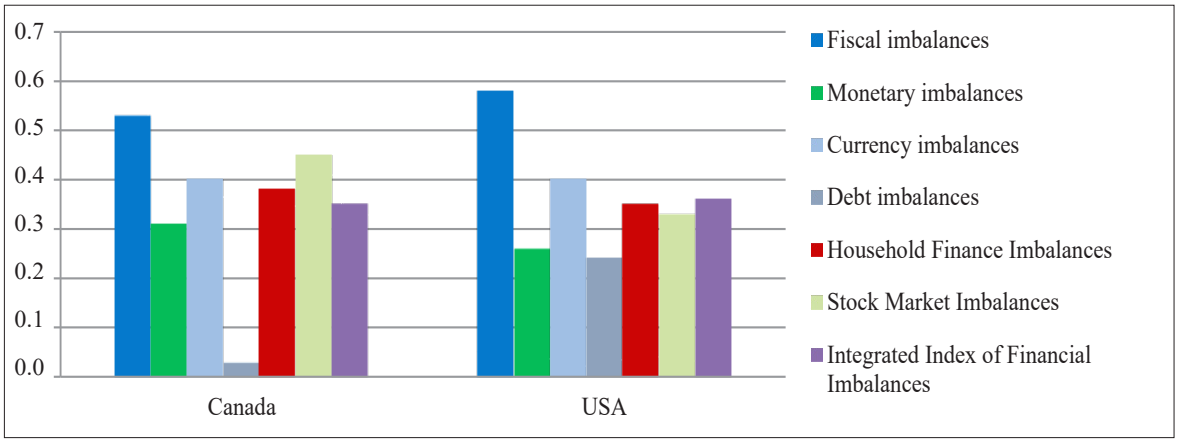

***Figure 12**. Integrated index of financial imbalances (I_{fimb}) by regions of North America, on average for 2013-2019*

***Source**: calculated by the authors based on Organisation of Economic Cooperation and Development; UNCTAD (2013; 2017; 2019)*

A high degree of financial imbalances can be seen in the economy of Ukraine (0.58), Brazil (0.57), moderate – in most of the studied countries (about 0.40-0.50), the lowest values of the integrated index of financial imbalances are for Qatar (0.32), Switzerland (0.33). At the same time, the peak points of imbalances were debt imbalances (Ukraine – 0.71), monetary imbalances (Brazil – 0.68) and imbalances in household finances (Mozambique – 0.74), stock market imbalances (African countries – more 0.87, Indonesia and Argentina – 0.75). It was found that developed countries, as well as countries making a transition to a dynamic model of development (China, Singapore) are characterised by a lower level of imbalance in the financial system, which may be associated with a higher level of development and use of economic regulatory instruments. The main factors of imbalance in less developed economies are the administrative intervention of state bodies, which violates the built-in market mechanisms of self-balancing of the economic system as a whole.

The correlation coefficient between the integrated index of financial imbalances and the share of attracted foreign investments in the structure of GDP by regions of the world is calculated (Fig. 13).

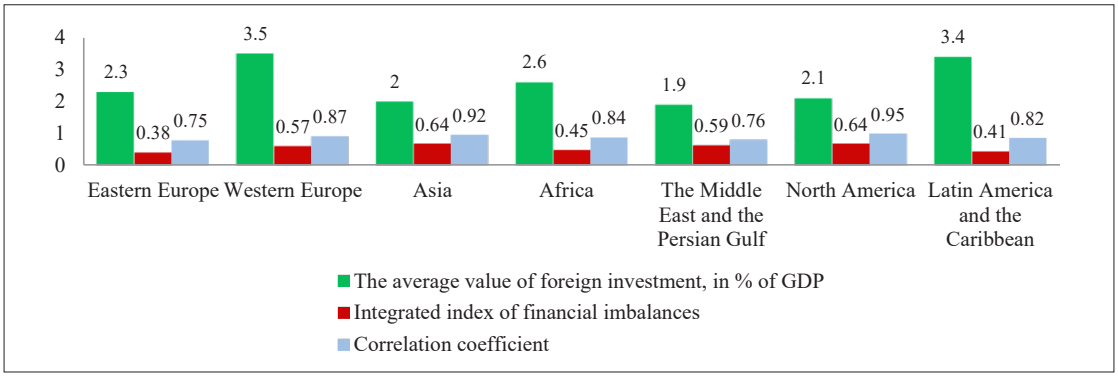

***Figure 13**. The impact of financial imbalances on the volume of foreign investment in the economy of the world*
***Source**: calculated by the authors*

Based on the results of the econometric study, the authors believe that global countries need to pay attention to further efforts to disclose the full potential benefits of incoming investment flows, as well as the feasibility of their redistribution between regional groups to promote economic development and stimulate investment, tax and exchange rate policies with the aim of regulation of foreign economic activity for effective use of attracted foreign investments. Comparable results are demonstrated by L.O. Pehkova (2018), where the researcher established that minimisation and overcoming of financial imbalances and qualitative improvement of the production potential of the real sector of economy will allow realising the competitive advantages of local products and world markets.

According to N. Bailey (2018), the globalisation of investment processes has a contradictory and divergent direction of influence on individual countries, their groups, industries and sectors of the national economy, and its advantages and disadvantages are disproportionately distributed worldwide, leading to the accumulation and deepening of financial imbalances, violation of the institutional and functional balance of the world economy and strengthening the multipolarity and multi-vector nature of its development. However, V.V. Koziuk (2018) believed that the directions of the process of capital transfer will not affect the national economies, provided that the attracted investments generate profit. Y. Komarynska et al. (2020) convinced that they are influential enough to service and repay existing external debt. Financial imbalances become dangerous if they are the cause of the accumulation of external debt. According to F. Economou (2019), all financial imbalances that are present or will potentially arise and those which may increase the risk of financial and economic crisis, are subject to quantitative identification. This requires the adoption of preventive and corrective measures to prevent the negative consequences of their manifestation.

CONCLUSIONS

Thus, global countries need to pay attention to further efforts to tap into the full potential benefits of incoming investment flows, as well as the feasibility of their redistribution between regional groups to promote economic development and stimulate investment, tax, and exchange rate policies with the aim of regulation of foreign economic activity for effective use of attracted foreign investments. To increase the efficiency of attracting foreign investment, structural reforms are urgently needed to improve the business climate of private investment. However, the real sectors of the world economy face more costly regulatory processes, difficult access to credit, weak investor protection and protection of property rights. Furthermore, access to information needed to address the complex challenges of stock market inequality, as well as fiscal, monetary and debt policies, causes financial imbalances for Ukrainian and international investors.

Determining the complexity of the situation in which most countries appear, attention should not be focused on security or geopolitical issues, but at the first stage of developing priority areas to minimise financial imbalances in the economy, their impact on global trends, long-term social-economic and investment-oriented development must be taken into account. The central element in limiting financial imbalances in the

economy should be the interaction of international and Ukrainian scenarios of investment attractiveness of industries that need an optimal model of attracting foreign investment to balance the financial system of individual sectors in regional groups to predict inertial macroeconomic growth indicators in the states, reduction of external and state debt and suspension of the debt crisis in general.

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Залучення іноземних інвестицій в умовах циклічної незбалансованості економіки

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Анотація. Іноземні інвестиції є важливим економічним ресурсом для багатьох країн, у тому числі для України. Актуальність дослідження полягає в необхідності вирішення проблем залучення іноземних інвестицій. Стаття спрямована на розгляд умов залучення іноземних інвестицій в умовах циклічної диспропорції світової економіки. За допомогою методу кореляційно-регресійного аналізу визначено вплив показників фінансових дисбалансів як у цілому, так і за окремими субіндексами. Виявлено наявні та потенційні фінансові дисбаланси (фіскальні, монетарні, курсові, боргові, торгові, домогосподарські, інвестиційні та заощаджувальні) в умовах загрози фінансово-економічної кризи. Визначено порядок оцінки фінансових дисбалансів в економічній діяльності країн світу та їх регіональних угруповань, які реалізують процес інвестиційно-орієнтованого розвитку. Для оцінки їх впливу на обсяг прямих іноземних інвестицій запропоновано комплексну методику розрахунку субіндикаторів фінансових дисбалансів, яка за сукупністю певних параметрів формує інтегральний індекс фінансових дисбалансів. Обґрунтовано методологічні підходи до визначення обмежувальних процедур накопичення фінансових дисбалансів, пов'язаних із переходом фінансової системи у стан фінансової небезпеки, з урахуванням бюджетної, валютної, грошово-кредитної та боргової складових. Комплексна методика розрахунку субіндикаторів фінансових дисбалансів в економіці передбачає ідентифікацію економічних ризиків на ранніх етапах за допомогою механізму оповіщення про порушення збалансованості фінансово-економічних систем країн-учасниць. Визначено пріоритетні напрями (нерухомість і професійні послуги) для залучення іноземних інвестицій з усього світу. Запропоновано геостратегічну матрицю залучення іноземних інвестицій країнами світу

Ключові слова: фінансово-економічна криза, бюджет, валюта, перерозподіл, реформи

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Demand Analysis for Cereal Crops in Ethiopia

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Abstract. Cereals are common in Ethiopian diets, but the people's consumption habits are complex, with no single crop dominating. Empirical analysis of cereal crop household demand is required to quantify household responses to cereal crop value changes and individual income changes. A purpose of this study is to assess demand for major cereal crops in Ethiopia using secondary data from Ethiopian Social Economic Survey 2018/19 (ESS) with 1700 households of cereal-growing consumers. This paper utilises descriptive statistics and Almost Ideal Demand System (AIDS) model to estimate demand parameters for major cereal crops. The empirical results showed that crop prices themselves, prices of other crops and demographic factors influence the share of grain expenditure. The estimated income elasticity of all sampled cereals is positive, and the Marshallian (unpaid) price elasticity is elastic while the compensated cross-price elasticity was inelastic. Household response to cereal crop demand decreases as commodity prices rise. Teff was the most price-sensitive commodity and classified as a luxury good because its income elasticity value was greater than one. Wheat, maize, and sorghum were designated as necessities, and all of the cereal crops studied in this work are considered normal goods. According to the study, the magnitude of price elasticity is greater than the expenditure elasticity of cereal crops. This implies that price has a greater influence than income. As a result, price regulation policies would be more effective than income targeting policies. Furthermore, the positive expenditure elasticity suggests that as income rises, so will demand for cereal crops. Policies aimed at increasing income would increase demand for cereals

Keywords: Almost Ideal Demand System model, elasticity, expenditure shares, price, income

*Corresponding author

INTRODUCTION

Cereals are Ethiopia's most important food crops in terms of cultivated area and production output. They are produced in greater quantities than other crops because they are the primary staple crop. Cereals contributed 88.52% of total grain production. Maize, Teff, wheat, and sorghum are the most important crops in Ethiopia, accounting for 28.75%, 17.11%, 15.86%, and 15.71% of grain production in 2019, respectively (CSA, 2019).

Teff is a cultural staple crop in Ethiopia because it is the most consumed cereal in most Ethiopian households (Amare, 2021; Esubalew & Tewabe, 2022). Its demand in Ethiopia has steadily increased due to population growth, average incomes, and urbanisation (Lee, 2018). Wheat and wheat products account for 14% of consumers' total caloric intake (FAO, 2014). Wheat demand rises as incomes rise, and wheat demand has increased significantly over the last decade (USAID, 2021). Maize dominates consumer caloric intake, accounting for 17-20% of total intake (World Bank, 2018). Although maize is the least desired cereal in urban households, it is widely consumed in rural households because maize flour is mixed with teff to make the national staple injera, and maize is half the price of wheat and teff. Sorghum is one of Ethiopia's most affordable cereals (FEDSNET, 2021).

In Ethiopia, economic growth and an increase in individual earnings significantly increase household budgets, food consumption quantities, and calorie intake (Worku *et al.,* 2017). Because food accounts for a larger part of the household budget in both urban and rural settings, Ethiopia experienced an unprecedented food price spike in early 2005, resulting in inflation. Food prices peaked during the 2007/08 global food price crisis and then fell by a negative 20% late in 2009 because of the government's short-term price regulation policy. After control was lifted in early 2011, food prices increased by 34.5 percent in September 2011. Food prices reached a new high of around 16% in September 2015 and February 2018. Food price increases were identified as a major source of concern. In household surveys, rising food prices were ranked as the first most significant economic shock (LSMS-ISA, 2017).

To reduce high and volatile food prices, the government has implemented several policies, including restricting traders from accumulating food in their stores and imposing price ceilings on essential foodstuffs; legal protection; protecting citizens and the business sector from unfair market practices and distorted market conduct; tariff reductions on imported foods, and lower domestic prices. These regulations, however, make it difficult for local farmers to get a better price and reduce biodiversity. Food price increases are harmful to urban consumers and net buyers (Tassew & Yisak, 2020).

Demand elasticity provides information on how individuals regulate their consumption bundles as a result of exogenous shocks in the economic environment. Subsequent changes in food consumption patterns pose considerable risks to the welfare of the poor, who subsist on inadequate calories and are struggling daily to maintain a healthy life (Yekin, 2020). Hence, exploring the responses of vulnerable and poor households to food crises and income change is necessary for designing a suitable policy (income-related policies or price-regulated policies) to improve household food security.

Various attempts on the concepts of demand analysis using a quadratic almost ideal demand system have been made in Ethiopia and other developing countries over time. For instance, Linh (2020); Kharisma et al. (2020); Vigani et al. (2019); and Alexandria et al. (2015) studied the cases of Vietnam, West Java, Kenya, and Romania, respectively. Sara et al. (2018) estimate cereal demand in Morocco using an almost ideal demand system model. In the context of Ethiopia, few studies have been conducted on food demand analysis (Nigussie, 2020; Vigani et al., 2019; and Yekin, 2020). Moreover, earlier studies focused on either food demand as a whole or a combination of them, such as teff, wheat, and other cereals or grains, vs. fruits and vegetables, and root crops.

The purpose of this study is to analyse the demand for cereal crops in Ethiopia using the 2018/2019 Ethiopian Socioeconomic Survey data (ESS).

MATERIALS AND METHODS

Source of information: The data for this empirical study came from the 2018/2019 Ethiopian Socioeconomic Survey (ESS) (fourth wave), which was collected by the Central Statistical Agency (CSA) of Ethiopia in collaboration with World Bank Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA). The estimation sample size was 1700 households chosen based on weekly consumption availability data for cereal crops such as wheat, teff, maize, and sorghum. The sample includes both urban and rural households from seven Ethiopian regions. The consumption data was combined with information on household size, age, gender of the household head, and literacy level of the household head.

Data analysis method. The analysis employed both descriptive and econometric techniques. The descriptive statistics described the sample households' expenditures, budget shares of cereal crops, and demographic characteristics. The specification and estimation of cereal crop demand equations required econometric techniques. It also investigated the impact of various socioeconomic factors on household demand for cereal crops.

Almost ideal demand system model. The use of demand systems allows for the modelling of total expenditure allocation among commodities given a specific budget. An empirical model of the demand system is required to apply demand theory in the real world. The Linear Expenditure System (LES), the Rotterdam model, the Indirect Translog System (ITS), the Almost Ideal Demand System (QUAIDS), and the Quadratic Almost Ideal Demand System (QUAIDS) are some of the most

popular and frequently found in literature demand analysis models.

Based on the characteristics of each model, the study used an almost ideal demand system to analyse consumer expenditure on the four cereal crops chosen. The reason for not using other demand models in this study is that the Linear Expenditure System (LES), linearity is one of the benefits of LES mentioned above, but linear Engel curves have a constraint when the income range is large (Kenneth *et al*., 2020).

The Rotterdam model system is like demand theory and can investigate cross-commodity relationships. However, because it is not derived from a specific utility or cost function, the model contradicts utility-maximising behaviour. Even though translog model has the merit of functional form flexibility, the considerable number of independent parameters causes serious estimation problem. The AIDS demand function is more easily estimated than other models because it adheres to demand theory principles.

The Almost Ideal Demand System (PIGLOG) class of demand models is determined from linear in log total expenditure indirect utility functions (Jean-Marc and Sebastien, 2015). The demand functions are derived from the budget share, which is mathematically explained as follows (1):

$$wi = \alpha i + \sum_{j=1}^{4} \gamma ij ln\,(Pj) + \beta i \ln\left\{\frac{M}{a(P)}\right\} + zk + \varepsilon i \quad (1)$$

where ωi is household expenditure share of teff, wheat, maize, and sorghum; αi is the intercept of the demand function; γij is the parameter of the price of j^{th} cereal crops; j and i, are the list of cereal crops; P_j is price for j^{th} cereal crop; βi is the coefficients parameter in the expenditure share of cereal crops; M is the total expenditure share of the household in all goods; P is the price index; $a(P)$ is the translog of price indices given in Equation (3); zk is the k^{th} household socio-demographic characteristics; εi is the random error with standard properties; αi, γij, βi are the parameters to be estimated in the model; i=1, 2, 3, 4; j=1, 2, 3, 4.

The dependent variable is the expenditure share for the i^{th} cereal crops, and is defined as follows (2):

$$Wi = \frac{Pi*Qi}{M} \quad (2)$$

where P_i is the price of i^{th} goods at time t; Q_i is the quantity of i^{th} goods at time t; M is the total expenditure of all commodities.

Price index can be defined as follows (3):

$$lnP *= \alpha + \sum ak\ lnPk + 1/2 \sum\sum \gamma jklnPk\ lnPj \quad (3)$$

Since Equation (1) is highly nonlinear, Stone's index may be substituted by the price index in empirical extensions. Hence the Stone's index is explained as follows (4):

$$lnP = \sum Wi\ lnPi \quad (4)$$

when the Stone's index is used in Equation (1), the model is termed as linear approximation of almost ideal demand system (LA/AIDS).

First, if $\Sigma\alpha j$=1, $\Sigma\gamma ij$=0, and $\Sigma\beta i$=0, the sum of budget shares is 1. Second, the homogeneity condition requires $\Sigma\gamma ij$ to be zero. Third, the symmetry constraint holds if γij=γij.

The Marshallian and Hicksian elasticities are estimated using the LA/AIDS model's estimated parameters; in this study case, the Marshallian (uncompensated) own price, cross-price, and expenditure elasticity of demand for cereal crops is given in equations (5), (6), and (7), as follows:

$$\varepsilon ii = -1 + \frac{\gamma ii}{wi} - \beta i \quad (5)$$

$$\varepsilon ij = \frac{\gamma ij}{wi} - \frac{\beta i}{wi} wj \quad (6)$$

$$\eta = 1 + \frac{\beta i}{wi} \quad (7)$$

On the other hand, the Hicksian (compensated) own price and cross price elasticity (eij) were also explained in equation (8):

$$eij = \varepsilon ij + \eta iwj \quad (8)$$

RESULTS AND DISCUSSION

Household characteristics. Table 1 revealed that the mean values of age of household heads and the family size were 43.2 years and 4, respectively, for the households surveyed. Out of the 1,700 sample respondents, 72.18% were male-headed and the rest 27.82%, were female-headed households. The location of the sampled households indicates that about 67.65% of the respondents were from rural Ethiopia and 27.82% were from urban areas. The educational level of the respondents also indicates that 93.4% of them were illiterate.

Table 1. *Demographic characteristics of household*

Variable	Obs	Mean	Std. Dev.	Min	Max
Household size	1,700	4.267059	2.233665	1	16
Age of household	1,700	43.24176	15.09884	15	97
		Frequency	Percent		
Sex	Male	1,227	72.18		
	Female	473	27.82		
Education	Illiterate	1,589	93.47		
	Literate	111	6.53		
Location	Rural	1,150	67.65		
	Urban	550	32.35		

Source*: own calculation from CSA data on 2018/19*

Expenditure shares and price of major cereal crops. The results in Table 2 indicate that the average expenditure of a household on cereal crops was 18.25 USD/week with a minimum expenditure of 2.77 USD/week and a maximum expenditure of 32.83 USD/week. On average, out of the total expenditure of households for cereal crops, 60% is spent on sorghum and maize while 40% is spent on *teff* and wheat. This implies that sorghum and maize earn the highest budget share as compared to *teff* and wheat, which account for 37% and 23%, respectively. As presented in Table 2, the price of teff has the largest mean and standard deviation, followed by wheat, while the price of maize has the smallest mean and standard deviation.

Table 2*. Expenditure shares and price of major cereal crops*

Variable	Obs	Mean	Std. Dev.	Min	Max
Expenditure share of teff (W_i teff)	1,700	0.2022	0.1757	0.0043	0.9509
Expenditure share of wheat (W_i wheat)	1,700	0.1965	0.1642	0.0007	0.9476
Expenditure share of sorghum (W_i sorghum)	1,700	0.3687	0.2030	0.0023	0.9863
Expenditure share of maize (W_i maize)	1,700	0.2326	0.1686	0.0032	0.9034
Price of maize (P_m)	1,700	0.4073	0.1812	0.1935	1.0271
Price of sorghum (P_s)	1,700	0.5095	0.2035	0.1935	1.1519
Price of teff (P_t)	1,700	0.9839	1.4257	0.6774	1.7742
Price of wheat (P_w)	1,700	0.6729	0.2082	0.3226	1.3426
Non-food expenditure	1,700	336.507	459.057	0.0000	51.9581
Total expenditure of household	1,700	18.246	16.8365	2.7742	32.8352

Note*: Price, non-food and total expenditure measured in USD. Expenditure share expressed in percentage*
Source*: Own calculation from CSA data on 2018/19*

Econometrics result. Estimated coefficients for AIDS model of cereal crops. The results in Table 3 show that the expenditure share of teff was decreased by 6.8% as the price of teff increased by 1%. A 1% increase in teff price increases sorghum expenditure share by 11.17% while decreasing maize expenditure share by 2.62%. Therewith, a 1% increase in sorghum prices reduces the expenditure share of sorghum by 2.9% and increases the expenditure of wheat by 3.05%. Similarly, 1% increase in maize price results in a 2.85% decrease in maize expenditure share, an 8.2% increase in teff expenditure share, and a 4.8% decrease in wheat expenditure.

Table 3*. Almost ideal demand system (AIDS) results*

Variable	Wi teff	Wi wheat	Wi sorghum	Wi maize
$ln\ P_t$	-.0681806***	-.017337	.1117001***	-.0261825*
$ln\ P_w$	-.0092193	-.0037448	.0027321	.010232
$ln\ P_s$	-.0132088	.0305426***	-.0297763**	.0124425
$ln\ P_m$	.0820025***	-.0480644***	-.0053979	-.0285401**
βlnx	.0557046***	-.002643	-.013028	-.0400336***
Family size	-.0032534	.0001565	.0016775	-.0020704
Age	.0007554***	.0000463	-.0005286	-.0002732
Sex	-.0279423***	.0133254	.0084813	.0061355
Edu	.0002364**	.0046042***	.0019459	-.0032967**
A	.1057278	.2859425***	.126516	.4818136***

Note*: (***), (**), (*) denotes the level of confidence at 1%, 5%, and 10%*
Source*: own calculation from Stata 15*

Table 3 indicates that the coefficients of total expenditure were significant and positive for *teff*, but they were negative for maize. This implies that, as the total expenditure increases by 1%, the budget share of teff also increases by 5.57%. In another way, if total expenditure increased by 1%, the maize budget share decreased by 4% by holding other factors constant. From the demographic characteristics, age and education positively affect the expenditure share of *teff* while sex negatively affects the expenditure share of *teff*. The *education* level of the household has positively and significantly affected wheat and *teff* expenditure shares and negatively affected maize expenditure shares.

Price elasticity of demand for cereal crops in the Marshallian model (uncompensated). The Marshallian own-price, cross-price, and expenditure elasticity for major cereal crop demands such as teff, wheat, sorghum, and maize are shown in Table 4.

Cereal price elasticity of demand. Own price elasticity refers to the proportion in a household's consumption in response to changes in food commodity prices.

The sign of one's own price elasticity should be negative, according to economic theory. Table 3 shows that the uncompensated own price elasticity demands of major cereal crops (teff, wheat, sorghum, and maize) are negative and elastic.

Table 4 *Uncompensated (Marshallian) and expenditure elasticity for cereal crops*

	Pt	Pw	Ps	Pm	Expenditure elasticity
W_i teff	-1.347***	-0.116	-0.139*	0.285***	1.28***
	(0.079)	(0.06)	(0.058)	(0.054)	(0.039)
W_i wheat	-0.088	-1.016***	0.159**	-0.24***	0.987***
	(0.077)	(0.059)	(0.057)	(0.053)	(0.037)
W_i sorghum	0.304***	0.016	-1.071***	0.001	0.965***
	(0.051)	(0.039)	(0.038)	(0.035)	(0.025)
W_i maize	-0.107	0.087	0.099*	-1.047***	0.828***
	(0.066)	(0.051)	(0.049)	(0.046)	(0.032)

Note*: (***), (**), (*) denotes the level of confidence at 1%, 5%, and 10%*
Source*: own calculation from Stata 15*

This implies that demand for these cereal crops is sensitive to changes in price. When the price of a crop rises by one unit, the quantity demanded drops by more than one unit. This contradicts T. Nigussie (2020) findings that demand for teff wheat and maize is inelastic in price results. Teff demand became more sensitive to price fluctuations as a result. A one-unit increase in the price of teff results in a 1.35-unit decrease in the quantity demanded by households.

Cereal demand elasticity of income (expenditure): *Income elasticity is defined as the percentage change in quantity consumed of a given commodity in relation to the percentage change in the household's income. One can determine whether cereal crops are inferior, essential, or luxurious to typical farm households using income elasticity*. The income elasticity of major cereal crops is presented in Table 4. The empirical results showed that the income elasticity of all selected cereal crops was positive and significant at 1% level of significance, indicating that these crops are normal goods. As we see from the result, the income elasticity of *teff* was 1.28, which is greater than one, implying *teff* is a luxury good to the household, while the income elasticity of wheat, sorghum, and maize were 0.987, 0.965, and 0.828, respectively. Therefore, maize, wheat, and sorghum are necessities. This result is in line with the finding of T. Nigussie (2020). He found that *teff* is considered a luxury good in most households in Ethiopia while maize and sorghum are necessities. Wheat, on the other hand, is a luxury good, which contradicts his discovery.

Cross-price elasticity of cereal crops. Cross-price cereal crops demonstrate the substitutability and complementarity effects of commodities by measuring the percentage relationship between price and quantity consumed in response to price changes. The value of zero indicates that the two products are independent, Positive cross-price elasticity indicates substitutability, whereas negative cross-price elasticity indicates complementarity. According to the empirical review findings, the uncompensated cross-price elasticity of teff with sorghum was negative, indicating that teff was consumed in addition to sorghum. However, it can be substituted for maize. Wheat is consumed in addition to maize and is substituted with sorghum. Sorghum was replaced with maize.

Estimation of cereal crops' compensated price elasticity. The percent change in demand for a good because of a price change that excludes the income effect is known as compensated or substitution elasticity. According to Table 5, the compensated own price elasticity of demand for teff,

wheat, sorghum, and maize is (-1.09, -0.822, -0.716, and -0.854). This showed that the elastic demand of teff was elastic (hence its elasticity is greater than zero in the absolute term), while the demands for wheat, sorghum, and maize were inelastic. The consequences of inelastic demand in wheat, sorghum, and maize demonstrate that these crops are critical to life. Household demand for those crops was less sensitive to price fluctuations. The decrease in quantity change in demand for those crops was less than the decrease in quantity change in price.

Table 5. *Estimated coefficient of compensated elasticity*

	Pt	Pw	Ps	Pm
W_i teff	-1.09***	0.135*	0.331***	0.582***
	(0.079)	(0.061)	(0.06)	(0.054)
W_i wheat	0.111	-0.822***	0.523***	-0.009
	(0.076)	(0.059)	(0.059)	(0.053)
W_i sorghum	0.499***	0.206***	-0.716***	0.226***
	(0.052)	(0.039)	(0.039)	(0.035)
W_i maize	0.06	0.25***	0.405***	-0.854***
	(0.066)	(0.051)	(0.051)	(0.046)

Note*: (***), (**), (*) denotes the level of significance at1%, 5% and (10%) level*
Source*: own calculation from Stata 15*

The compensated cross-price elasticity of teff to wheat, maize, and sorghum had positive signs, indicating that these goods are substitutes for one another in the estimated mean shares. Teff, wheat, and maize are used in place of sorghum in households. Similarly, wheat and sorghum were discovered to be maize substitutes. On the contrary, T. Nigussie (2020) results reveal that teff and wheat is complementary to each other but substitutable for maize and sorghum.

CONCLUSIONS

The analysis of the determinants of cereal crop demand and estimation of elasticity, especially with respect to income and prices, provides vital information regarding the consumption behaviour of society in general. In this regard, the authors estimated the demand for cereal crops in Ethiopia based on secondary data obtained from the 2018/2019 Ethiopian Socioeconomic Survey (ESS) fourth wave with a sample size of 1700 households. To examine household demand for cereal crops, the study implemented the Almost Ideal Demand System (AIDS). The AIDS results revealed that price, expenditure, and demographic factors such as age, sex, and education level of household headed influenced Ethiopian household demand for cereal crops. The results of uncompensated own-price elasticity revealed that all selected cereal crops had elastic demand.

Household response to the demand for cereal crops decreases as the commodity price increases. The most responsive commodity to price change was *teff*, followed by sorghum, maize, and wheat. However, all cereal crops except teff were inelastic in the compensated price elasticity result. All the cereal crops chosen were classified as normal goods, with an income elasticity value greater than zero. Wheat, maize, and sorghum were classified as necessity goods due to their commodity nature, while teff was classified as a luxury good due to its income elasticity value being greater than one. The cross-price elasticity result showed that most of the sampled crops were substituted for each other. Teff was consumed with sorghum and substituted for maize. Wheat and sorghum were substituted for maize. Wheat and maize are also substituted for each other.

The implications derived from this finding were that the magnitude of price elasticity is greater than the expenditure elasticity of cereal crops. It can be inferred from these results that price has a higher impact than income. Thus, the price regulating policy would be effective over income targeting policies. The positive expenditure elasticity suggests that the demand for cereal crops is likely to expand as income increases. Policies that target income growth would lead to higher demand for cereals.

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Аналіз попиту на зернові культури в Ефіопії

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Анотація. Зернові культури поширені у раціоні харчування жителів Ефіопії, проте споживчі звички населення складні, і жодна з культур не переважає. Емпіричний аналіз попиту домогосподарств на зернові культури є необхідним для кількісної оцінки реакції на зміну вартості зернових культур та індивідуальних доходів. Мета даного дослідження – оцінити попит на основні зернові культури в Ефіопії, використовуючи вторинні дані Ефіопського соціально-економічного дослідження 2018/19 (ESS) із 1700 домогосподарств споживачів зернових культур. У цій роботі використовується описова статистика і модель майже ідеальної системи попиту (AIDS) з метою оцінки параметрів потреби в основних зернових культур. Емпіричні результати показали, що на частку витрат на зерно впливають самі ціни на зернові культури, ціни на інші культури та демографічні фактори. Розрахункова еластичність доходу всіх відібраних зернових є позитивною, а еластичність маршаллівської (неоплачуваної) ціни є еластичною, тоді як компенсована перехресна цінова еластичність виявилася нееластичною. Реакція домогосподарств на потребу в зернових культурах знижується зі зростанням ціни товару. Тефф був найбільш чутливим до цін товарів і класифікувався як предмет розкоші, оскільки значення еластичності доходу було більше одиниці. Пшениця, кукурудза та сорго були визначені як предмети першої необхідності, а всі зернові культури, досліджувані в цій роботі, вважаються звичайними товарами. Згідно з дослідженням, величина цінової еластичності більша, ніж еластичність витрат зернових культур. Це означає, що ціна має більший вплив, ніж дохід. У результаті, політика цінового регулювання буде більш ефективною, ніж політика цільового доходу. Крім того, позитивна еластичність за витратами передбачає, що зі зростанням доходів зростатиме і попит на зернові культури. Політика, спрямована на підвищення прибутків, збільшить попит на зернові культури

Ключові слова: модель майже ідеальної системи попиту, еластичність, частка витрат, ціна, дохід

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Dynamics of Development of Production and Export of Agricultural Products in the Context of Foreign Trade in Australia

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Abstract. The agricultural sector is one of the main branches of the Australian economy and of the country's exports. This contributes to the considerable level of agricultural development and resource specialisation in international trade in general. Ukraine in this respect is like Australia, which makes the current state of the agrarian sector in both countries relevant. The purpose of this study was to investigate the state of the agricultural sector in Australia and find elements of development that would help change the Ukrainian agriculture. Statistical methods, such as graphical and statistical analysis, became the main methods in the study. This is conditioned upon the formation of conclusions mostly based on statistical information, graphs and tables presented in the article and constructed with statistical TradeMap. During the study, the author concluded that the fate of agricultural exports in the country was reduced due to the current orientation of the country towards the export of resources, namely iron. Within the structure of export of agricultural products, considerable changes are taking place, the main of which is the transition to production of animal products. Ukraine may adopt some features of the sector in Australia, namely how the country is conducting investment policy in the sector. Nevertheless, it was found that there are significant differences in the agricultural sector of both countries. Because of this, it is impossible to completely change the plan of operation of the Australian agriculture. Research on the future development of the industry in Australia, considering current trends and their impact on foreign policy and trade in the country, may be promising. This article will be useful for studying the functioning of the economy of Australia and Ukraine, namely their agricultural sectors; to form the national policy of the agrarian sector and foreign trade; for students to learn economic disciplines and write corresponding theses

Keywords: agricultural sector, economy, resources, international trade, population

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INTRODUCTION

The agrarian sector of the country's economy is an integral complex intricately connected with natural conditions, resources, technical capabilities, and qualified specialists aimed at the production of livestock and plant-growing products (Evans *et al.,* 2019). For any country, agriculture is the leader in economic development (Boulay & Lenoir, 2020; Kumar & Khanna, 2019). This was especially true in the period of subsistence economy when all gross domestic product (GDP) of the country was formed at the expense of this sector. This is not the case currently, as other industries (e.g., IT) generate more added value (Bandiera & Tsiropoulos, 2020). The figures confirm that: in 1958, agriculture occupied 25% of employment and formed 14% of GDP, while in 35 years these figures changed to 5.7% and 2.5% (Yang *et al.,* 2021). However, for developing countries, where agriculture is often low-intensive, with low yield, and unable to attract investment, the development of this sector is one of the main ways for future prosperity (Mimken & Belmar, 2020). This sector is quickly and relatively easily equipped, and its development leads to a significant improvement in the living standards of the local population. For scientists all over the world, agriculture is one of the important components for achieving the concept of "sustainable development" (Freire *et al.,* 2022; Ara *et al.,* 2021).

Australia is a special country in this case. It is a highly developed country, but it is still a significant exporter of raw materials (similar to developing countries): the main types of resources exported in 2020 include steel, slag, ash, different types of materials, precious metals, and agricultural products (Trademap, 2022; Malerba *et al.,* 2022). The reason for this specialisation of the country is its late opening (Cassman & Grassini, 2020). The first expedition to the continent, conducted by the Dutch, was launched only in 1606, the first British colonies were founded in 1788, and in 1931 under the Westminster Statute (which the country ratified in 1942) Australia became virtually independent from the UK (Cohen *et al.,* 2019). Due to the late opening of the continent, many of its minerals stay unexplored. In this Australia is like Canada and America (Su *et al.,* 2021; Brown & Cunningham, 2019). However, the business in agriculture is going on. The country has long-standing landscapes with soil, and the climate of most of the territory is dry and very variable from year to year (the rains fall a little and they are not stable); therefore, the soil in the country is low-fertile (Ibn-Mohammed *et al.,* 2021; Ranjbari *et al.,* 2022). It is possible to compare Australia with Ukraine, which is also specialised in agricultural production but has quite different natural and climatic conditions, and much more fertile soils (Chancellor *et al.,* 2021; Koshkalda *et al.,* 2020). The technological part of agriculture grows rapidly and has recently come to use nanotechnology, which helps to create hybrids of existing plant species, increasing their economic value (Palamarchuk *et al.,* 2021; Antle, 2019). The use of manual labour is still widespread in Ukraine, which, despite all climatic advantages, makes the agricultural sector of Ukraine much less competitive.

Ukrainian agriculture is at an important stage today, which is connected primarily with the official opening of the land market in 2024 (Kaminskyi *et al.,* 2020; Reznik & Oleksandr, 2020); besides, the country has considerable potential for the development of this sector, and prerequisites for further development (Mykhailenko & Kinchenko, 2019). For Ukraine, increasing the competitiveness of its domestic enterprises in the external markets to achieve the main goals (development of business and trade support services; creation of favorable conditions that stimulate trade and innovation for export diversification) still is extremely important (Khodakivska *et al.,* 2022). As the country's agriculture is actively involved in international economic integration and is beginning to play an increasingly significant role in economic development (Patyka *et al.,* 2021), consideration of the development of Australia's agriculture in the context of its foreign trade and the use of its experience for further reforms is relevant.

The purpose of this study was to demonstrate the state of the agricultural sector in the country and how its practices can be applied in the current conditions of Ukrainian development.

MATERIALS AND METHODS

When authoring this article, the main methods of research were empirical. Among them, it is possible to distinguish the graphical method and statistical observation, which are based respectively on the construction of graphs for the formation of conclusions and research of statistical data in general. The theoretical methods, such as analysis (works of scientists from different countries, as well as data on the development of foreign trade in Australia); historical (research in time of changes in the Australian and Ukrainian agriculture); forecasting (future changes in the agrarian sector of countries), induction and others. The study itself comprised three main stages. The first shows the key features of the development of Australian agriculture in general. The second stage features the statistical analysis of the country's exports and in particular its agricultural products. Based on the first two stages, conclusions were drawn of the agrarian sector and the probable trends in its development. In the last part of the study, the agricultures in Ukraine and Australia were compared by borrowing the Australian practices of development of the sector.

In analysis of dynamics of export of Australia, the indicator which can be called "the concentration ratio of export" was used. It shows how specialised the country is and how dependent on the export of certain

types of goods. The conditional formula for determining this indicator (Eq. 1):

$$W_n = \frac{\sum_{i=1}^{n} Ex_n}{Ex} \quad (1)$$

where W_n is the "the concentration ratio of export" of the first n export positions; Ex_n is the monetary expression of the n^{th} position in the export of the country; $\sum_{i=1}^{n} Ex_n$ is the sum of the first n export positions in the currency expression; Ex is the whole export of the country in the currency expression.

The larger this indicator is, the more concentrated on certain types of products are the exports of the country. Although the country must specialise in the production, diversification of exports (or entire economies) is also a vital component, as it is less dependent on changes in prices for goods and resources in the international market. Therefore, it is important to support the balance between export specialisation and diversification. This is especially relevant for countries that specialise in exporting resources, to which Australia belongs.

Statistical data for analysis was taken from an open Internet source called TradeMap (Trademap, 2022). Therefore, the classification is formed based on this source. Thus, the following formation is used in the study: "animal wool, fine or coarse wool; yarn of horsehair and fabric", however, it is not specified exactly how much wool or yarn has been exported separately; this also applies to other complicated indicators (with separate exceptions). Most of the data in the study is represented by graphs and tables of data on which conclusions are drawn. The categories marked with * and "not fully specified" are the same on the TradeMap site (the complete list of products in these components is not listed on this statistical Internet source).

RESULTS AND DISCUSSION

In the context of this study, it is worth considering the composition of export of trade in Australia. Table 1 shows how the fate of some goods in the export structure of the country has changed over the past 5 years.

Table 1 shows that the concentration of exports has increased significantly over the past five years, i.e., the amount of money that the country receives from exports of the first n goods has increased. This is detailed in Table 2.

***Table 1**. Dynamics of change of share of some types of goods in export of Australia, %*

Number n	Year	2016	2017	2018	2019	2020
	All exports	**100**	**100**	**100**	**100**	**100**
1	Ores, slag, and ash	25.76	26.19	23.50	28.91	35.66
2	Mineral fuel, mineral oil, and products of distillation	25.10	29.14	34.64	32.61	25.95
3	Natural or cultured pearls, precious or semiprecious stones, precious metals	8.33	6.69	6.31	6.62	7.68
4	Meat and edible meat co-products	4.36	3.97	4.02	4.25	4.09
5	Inorganic chemical; organic or inorganic compound of precious metals, rare earth metals	3.07	2.47	1.80	1.71	2.10
6	Cars, mechanical gauges, nuclear power reactor, boilers; its details	2.58	2.02	1.90	1.77	1.72
7	Cereals	2.69	2.87	1.90	1.26	1.50
8	Pharmaceutical products	1.25	1.10	1.17	1.39	1.36
9	Electrical machines, equipment, and its details; sound recorders and reproducers	1.42	1.36	1.27	1.29	1.22
10	Aluminium and aluminium products	1.52	1.37	1.51	1.21	1.20
11	Optical, photographic, cinematic, measuring, medical, surgical, and other equipment	1.53	1.34	1.25	1.22	1.16
12	Cooper and cooper products	1.30	1.11	1.14	1.13	1.08
13	Other goods	20.03	19.34	18.60	16.66	14.34

***Source:** compiled by author based on TradeMap data*

***Table 2**. Dynamics of changes of the first 1, 3, 5, 7 and 10 positions in export of the country*

Year		2016	2017	2018	2019	2020	Difference (2020-2016)
Number n	1	25.76	26.19	23.50	28.91	35.66	9.9
	3	59.19	62.01	64.44	68.14	69.29	10.1
	5	66.62	68.45	70.26	74.09	75.48	8.86
	7	71.89	73.34	74.06	77.12	78.70	6.81
	10	76.09	77.17	78.01	81.01	82.48	6.39

***Source:** compiled by author based on TradeMap data*

As Table 2 demonstrates, the concentration of exports in the country is increasing at a significant rate. This leads to a certain danger for the Australian economy because it means a gradual decline in economic diversification. However, to conclude on the extent of diversification, it is necessary to compare it with other countries. This is presented below in Table 3.

***Table 3**. Export concentration index (first 1, 3, 5, 7, and 10 items in exports) of some countries as of 2020, %*

Number n	Country									
	Australia	USA	China	Russia	Ukraine	German	Canada	France	Japan	India
1	35.66	12.82	27.41	42.10	19.07	17.14	17.67	11.51	19.11	10.03
3	69.29	34.85	48.63	62.77	46.30	43.47	36.90	28.92	54.08	25.60
5	75.48	48.10	55.45	70.29	60.41	55.96	47.93	43.00	66.33	38.45
7	78.70	58.03	61.31	75.18	68.01	62.53	54.56	50.81	73.87	48.05
10	82.48	68.88	69.22	80.55	75.84	68.63	62.40	60.56	80.17	57.45

***Source:** compiled by author based on TradeMap data*

Table 3 shows that among the ten countries considered, Australia is one of the most concentrated. Similar to it by concentration level are other countries specialising in the export of resources, namely Russia and China. It is also interesting that Canada, which is also a resource-exporting country, is much less concentrated in other countries. This suggests the danger of Australia's dependence on resource prices on its economy. Next, the study considered the dynamics of foreign trade in Australia by agriculture. Fig. 1 shows the schedule of changes in the share of agricultural production to the whole exported production, and Fig. 2 shows the number of products in billions of dollars.

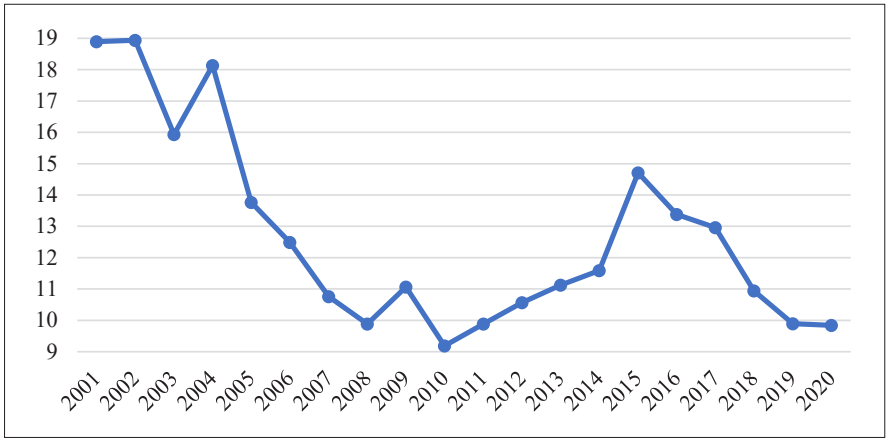

***Figure 1**. The percentage change of the share of agricultural production to the whole export production from 2001 to 2020, %*
***Source**: compiled by author based on TradeMap data*

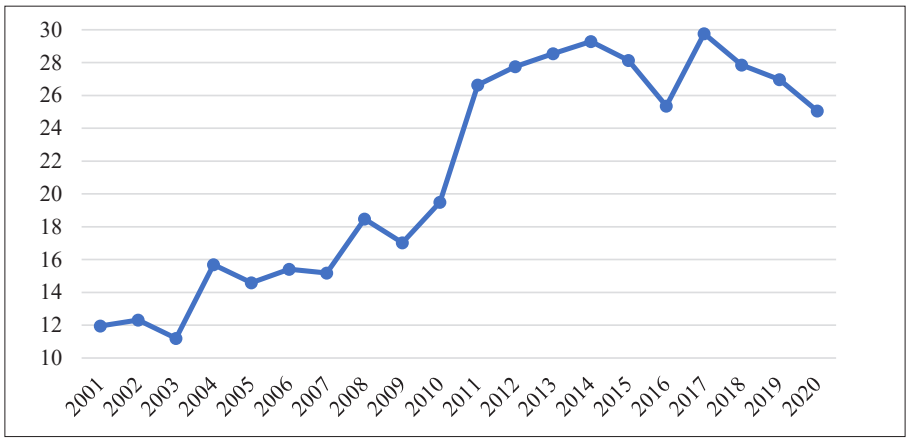

***Figure 1**. Absolute change in quantity of exported products from 2001 to 2020, million dollars*
***Source:** compiled by author based on TradeMap data*

As the two graphs show, the share of agriculture export is much lower (twice) than the country's total exports, while the total number of products increases each year (also twice). This is presented in the following Fig. 3.

Analysing other types of export crops in the region, the author concluded that such changes were due to a significant increase in the export of raw materials, namely, ore, slag, and ash. In 2001, only 8.1% of total exports were involved in this type of export, and in 2020, 35.7% were engaged. This role was also played by an increase in the export of diverse types of minerals from 20% of exports to 25%. Figure 4 shows the growth rates of these two types of export crops compared to the export of the whole country and the agricultural sector.

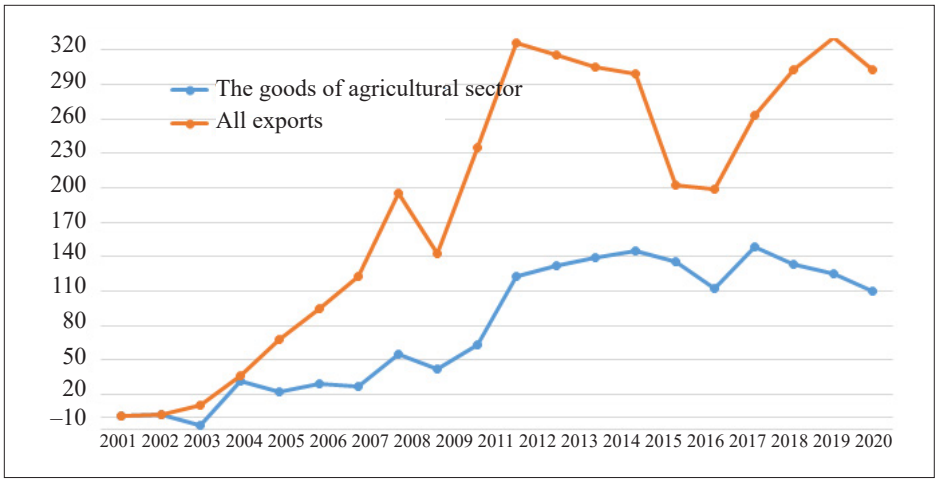

***Figure 3**. Comparison of growth rate of total export of Australia with growth of export of products of agrarian sector, % growth*

***Source:** compiled by author based on TradeMap data*

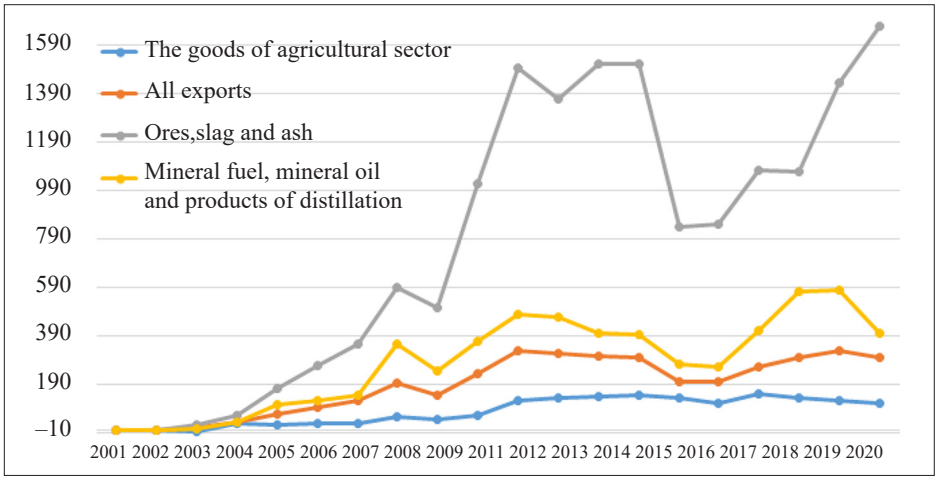

***Figure 4**. Export of certain types of Australian products from 2001 to 2020, % growth*

***Source:** compiled by author based on TradeMap data*

According to the graphs, we see that the export of ore, slag, and ash has increased more than 17 times over the last 20 years. This is a significant increase in the concentration of the country's exports. In TradeMap this group is recorded as "Ores, slag and ash", therefore it is difficult to say, what was the reason for such a sharp increase. Nevertheless, there is a considerable likelihood that this is due to the growth of iron ore production in Australia: According to USGS (United States Geological Survey), Australia is the largest exporter of iron ore in the world (USGS, 2022). New iron-ore mines are being opened in the country every year, the extraction of this type of resources is increasing; the so-called "boom" of mining of minerals (Helleiner, 2021) is taking place. Because of this, it is not surprising that the income of Australia will depend on the price of this kind of raw material.

It is also worth considering the export of agricultural products in terms of its separate components. They are shown in Table 4 below.

***Table 4**. Exports of major agricultural products from 2001 to 2020, % of the share of agricultural exports*

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Meat and edible meat products	27.19	25.96	30.31	30.15	35.25	34.14	36.07	32.40	30.21	31.31
Cereals	24.72	23.77	17.99	26.17	19.98	22.39	14.74	23.73	25.99	24.15
Fruits and nuts; citrus peels or melon	2.60	3.01	3.27	2.64	3.24	2.98	3.21	2.63	3.52	2.78
Animal wool, fine or coarse wool; yarn of horsehair and fabric	15.42	16.06	15.00	12.17	12.21	11.66	15.26	10.47	8.53	10.55
Seeds of oil and oil fruits; different seeds and fruits	5.69	5.68	4.54	5.67	4.37	4.08	2.90	4.92	7.12	5.37
Animals	4.45	5.16	5.63	3.88	4.28	4.32	5.14	5.10	5.31	5.40
Wood and its products; charcoal	4.63	5.24	6.64	5.92	6.52	6.55	7.85	7.00	5.74	6.45
Export of other agricultural products	15.31	15.13	16.62	13.41	14.15	13.88	14.83	13.74	13.58	13.99
Age	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Meat and edible meat products	27.40	26.97	29.60	35.89	35.38	32.58	30.60	36.74	42.93	41.54
Cereals	30.28	31.25	28.41	25.47	23.00	20.08	22.13	17.40	12.77	15.19
Fruits and nuts; citrus peals or melon	2.08	2.57	3.57	3.72	4.96	5.48	4.91	5.69	7.00	6.80
Animal wool, fine or coarse wool; yarn of horsehair and fabric	11.06	9.54	8.96	7.50	7.89	8.96	9.65	10.72	8.38	6.37
Seeds of oil and oil fruits; different seeds and fruits	7.52	9.13	10.62	6.66	6.17	5.88	6.46	5.43	4.66	5.59
Animals	4.15	3.95	3.59	5.05	4.81	5.64	4.16	4.92	5.52	5.41
Wood and its products; charcoal	4.68	3.70	3.60	4.23	4.46	5.55	5.56	6.47	6.31	5.40
Export of other agricultural products	12.84	12.89	11.66	11.49	13.33	15.84	16.53	12.62	12.43	13.71

***Source:** compiled by author based on TradeMap data*

Evidently, in 2020 the main share of agricultural exports began to occupy the category "Meat and edible meat products" (increased by 52%), although in 2001 the share of this position was equal to the fate of "cereals" (the category "cereals" decreased by 38.5%). Furthermore, the share of "fruits and nuts; citrus peel or melon" increased by 2.5 times, from 2.6% to 6.8%. Exports of wool, yarn, and horsehair (about 2.5 times) decreased significantly. Other main types of export products of this type are at the same level.

Thus, the country was oriented toward the production of both cereals and meat, now it is specialised in the production of meat products. This is due to the specific features of the Australian climate and soils, under which it is more effective to export livestock products.

Australian agriculture has a brief history compared to most large agricultural countries. From the beginning of the settlement on the mainland it developed slowly, and from 1788 to 1900 reached only the volume of 2 million ha. In modern times this figure exceeded 23.5 million ha (Ibn-Mohammed *et al.,* 2021). At present, Australia is a significant exporter of agricultural products, including beef, wheat, sugar, wool, barley, dairy products, and wine. About 60-70% of production is exported, the reason being a low internal market of only 25.72 million people (Statista, 2022). Therefore, the complex climate situation has led to the existence of an interesting system of functioning of agriculture, which since the beginning of the 20th century forms farmers as beneficiaries of innovations (Pruntseva *et al.,* 2021; Ritter *et al.,* 2020). These conditions also contributed to the formation of resource-saving agriculture, aimed at reducing soil cultivation and increasing crops by improving their fertility (zero or minimum soil treatment, harvesting of grain, oil, and legumes, etc.).

J. Freebairn (2021) notes that Australia is currently experiencing climate change. This may lead to lower returns from land, and thus reduce the effectiveness of the agricultural sector of the country. The country is preparing for this, and therefore conducts several types of procedures that ensure land adaptation. According to E.-M. Meemken & M.F. Bellemare (2020), these procedures differ from territory to territory because of differences in soil types, but one thing is to preserve the efficiency of agriculture. The government supports farmers, provides them with information on climate change, weather forecasts, supports the development of innovative technologies, and provides social support to those who are unable to adapt. The peculiarities of investment in agriculture in Australia are that the main investors in the country have always been foreigners. Local investors were more inclined to invest in mining. In turn, E. Helleiner (2021) believes that the reason for this is that local managers of Australian funds had very short-term

views on agriculture and investment in it, while foreign governments and funds bought Australian farms and food assets.

Since the year 2025, demand for agricultural products in the country is expected to increase, especially among foreigners (companies from New Zealand, China, the USA, and others). Because of this, Australia must prepare to make more investments and produce more products in this sector in the country (Bourman *et al.,* 2022). Currently, a large part of the farms in the country is family-based. Nevertheless, they show good stability indicators even in adverse climatic conditions, such as drought, flooding, increased salt content, etc. (Dreccer et al., 2018). Nevertheless, commercial, non-family farms stay the most productive; therefore, one of the most important goals of the country is to turn family farms into more efficient ones. The Australian authorities believe that this model is outdated, and the state should form a strategy for agricultural development based on European models (Allen *et al.,* 2019).

There is some concern among the local population about significant volumes of foreign investment in the country, which the state authorities are also paying considerable attention to. This concern is caused by the fact that foreigners do not adhere to the environmental standards of the country, thus jeopardising the productivity of the sector in the future. Because of this, the country needs to create a more attractive investment climate for local investors. According to J.-O. Hesse (2021), the methods that can help to encourage investments among the local population are reduction of the rate of income tax on investment activity (or provision of other financial benefits), simplification of the investment process (filling of some documents in particular), provision of guarantees on the preservation of investments in case of emergencies and others. Until such measures are taken, foreign investment will prevail in this sector.

Having analysed Australia's agriculture over the past few years and its state in the country, some features of the country's agricultural sector and lessons for Ukraine can be found. Under the entry into force of the Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine Concerning the Circulation of Agricultural Land", the country has approached to a considerable extent the European model of functioning of the "land market" (Litvinova & Chuenko, 2021). Since the collapse of the Soviet Union, politicians have often discussed the possibility of buying all land by foreigners, which, according to their beliefs, would lead to total poverty in the population. I. Arto et al. (2022) explained this by the fact that the new owners of the land will force the local population to work for small money and at the same time make huge profits. Nevertheless, the authors of this article do not agree with this statement: new foreign investments will lead to added tax revenues to the budget, creation of new jobs, and development of local infrastructure. M. Frattaroli (2020) agrees with the fact that national investors should also own state land and conduct business on it. The situation that has existed in Ukraine in recent years, under which the land market did not exist, has enabled local government officials or politicians to carry out various corrupt operations related to the sale or lease of land. S. Hsiang et al. (2019) are convinced that the opening of the land market and the establishment of a fair price will in turn reduce the opportunities for the authorities to carry out such operations.

As Tables 1, 2, and 4 clearly demonstrated, Australia is strengthening the processes of specialisation, which are reflected in the increase in export. O. Anysenko & K. Vakar (2018) confirm that in Ukraine, they are also happening: the share of steel and iron in exports decreases over time, and the share of agricultural products (in particular, cereals and oils) increases; there was a considerable increase in the country's agricultural sector, although in the future the development of this sector in the future, according to some scientists, there is uncertainty. Although both countries specialise in agricultural production, they have quite diverse cultures in their exports. This shows once again that Ukraine should choose its own path, which will differ in many respects from the Australian development of this sector.

CONCLUSIONS

The study showed that the basic agricultural sector of the economy of Australia is family farms, which produce the absolute majority of the industry's products. They are also the main initiators of innovation change, which should be constantly carried out, in connection with the special climatic conditions. Another feature is that foreign investment prevails in Australia's agriculture. This raises some concerns among the local population. That is why the country aims to increase the investments of local investors in the industry.

In export countries, the resources of diverse types predominate, mainly – "ore, slag and ash", and in particular – iron ore (due to a considerable amount of this resource in the country and the rise in prices for it in recent years). However, agricultural products also occupy a significant part of exports. The foreign trade in agricultural products is also marked by significant changes. Previously, the share of exported meat and cereals was the same, while the current meat exports almost tripled over the cereal exports. Thus, we can talk not only about increasing the specialisation of Australia as a whole (which was also shown in the study based on export concentration) but also in certain sectors. In the future, this could pose a threat to the country in case of a crisis in the world markets, as well as bring benefits during the economic upturn. Therefore, the country needs to strike a balance between these two indicators.

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Динаміка розвитку виробництва і експорту продукції сільського господарства в контексті зовнішньої торгівлі Австралії

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Анотація. В Австралії аграрний сектор є одним із основних в економіці та, зокрема, експорті країни. Сприяє цьому значний рівень розвитку сільського господарства в країні та її ресурсна спеціалізація в міжнародній торгівлі в цілому. Україна в цьому аспекті є подібною до Австралії, що робить актуальним розгляд сучасного стану аграрного сектору в обох країнах. Метою статті є детальний аналіз аграрного сектору в Австралії та знаходження елементів розвитку, що допомогли б модифікувати українське сільське господарство. Основними методами при написанні роботи стали статистичні методи, такі як графічний і статистичний аналіз. Це пов'язано із формування висновків в більшості на основі статистичної інформації, графіків та таблиць, показаних в роботі, та побудованих за допомогою статистичного TradeMap. У ході дослідження автори дійшли висновку щодо зменшення долі експорту аграрного сектору в країні, що пов'язано з сучасною орієнтацією країни на експорт ресурсів, зокрема заліза. Усередині структури експорту продукції сільського господарства відбуваються значні зміни, найважливішою з яких є перехід до виробництва продукції тваринництва. Україна може перейняти деякі особливості функціонування даного сектору в Австралії, зокрема те, як у країні ведеться інвестиційна політика в галузі. Тим не менш, було з'ясовано, що в сучасному сільськогосподарському секторі обох країн існують значні відмінності. Через це повністю переймати план функціонування австралійського сільського господарства неможливо. Перспективними можуть стати дослідження в питанні майбутнього розвитку галузі в Австралії з урахуванням сучасних тенденцій, та їхній вплив на зовнішню політику та торгівлю країни. Стаття стане корисною для вивчення функціонування економіки Австралії та України, а зокрема їхніх сільськогосподарських галузей; для формування державної політики аграрного сектору та зовнішньої торгівлі; студентам – для вивчення економічних дисциплін та написанні відповідних робіт

Ключові слова: аграрний сектор, економіка, ресурси, населення

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Financial Discipline at all Levels of Government: Test with Focus on Poverty Reduction in Nigeria

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Abstract. In Nigeria, the improper use of government resources has proven to be a big concern. While residents live in abject poverty, it is important to highlight that the government at all levels generates adequate resources to eradicate poverty in the country provided there is strong administration and financial discipline. This study examined the efficiency of government independent resources at all levels in poverty reduction. The purpose of this study was to test the impact of the independent government resources on poverty reduction. The study covered a period from 2007 to 2020 using secondary form of data. The autonomous income of each level of government was obtained from Central Bank of Nigeria Statistical Bulletin while the per capita income used as proxy for poverty control was collected from the World Bank Development Indicator. The study applied multiple regression approach in examining the influence of government resources at all levels on poverty reduction. Consequently, the regression result showed that each level of government generates resources capable of reducing poverty in Nigeria. The authors of this paper recommended financial discipline, strong governance, and resource conservation. This was the first study to explore monetary ceiling and to use government independent resources at all levels in assessing the role the government may play in decreasing poverty in Nigeria, using the available resources at each level of government in the country

Keywords: fiscal restraint, resource management, government levels, poverty control

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INTRODUCTION

Nigeria's weak economic standing has necessitated budgetary austerity at all levels of government. In Nigeria, resource waste, embezzlement, and misappropriation of government finances have caused excessive hardship for the ordinary people, resulting in increased unemployment, distinct types of insecurity, and people living below the poverty line. As a result, the quantity and quality of government spending have not resulted in long-term development or improvements in individuals' well-being (Agri *et al*., 2020). Nigeria's poor status has prompted a need for fiscal restraint while proper allocation of resources has become necessary at all levels of government. Thus, there is urgent need for financial discipline as a tool to manage the poor condition of the country. Financial discipline may be defined as cautious and prudent spending, proper resource control, and stringent money management to reach predetermined goals. Financial discipline also means the capability to stick to one's savings and investment strategies to meet one's financial objectives. Access to finance promotes inclusive strategy that allows economic actors to participate in long-term community-oriented investment projects, facilitate efficient allocation of economic capital and thus lower the cost of capital, properly deal with unprecedented short-term disruptions, drastically enhance day-to-day financial planning, and reduce typically rapacious informal sources of finance (Demirgüç-Kunt *et al*., 2018; Demirgüç-Kunt *et al.,* 2015; Kalachevska *et al.,* 2022). It does not indicate a misalignment of goals or a misallocation of resources if economic initiatives are carried out and supervised to minimise financial waste.

The three echelons of administration in Nigeria have economic independence to an extent that the constitution allows for autonomous income collection. It is prescribed that financial discipline would be used wisely throughout the process to lessen the amount of economic suffering that residents endure daily. This subject has been examined in a number of indigenous studies, with some findings indicating that government spending has a good impact on poverty alleviation (*Agri et al*., 2020; Chude, Chude & Arinze, 2019), while others suggest that the level of government spending on basic economic sectors due to poor budgeting policy do not alleviate poverty in Nigeria (Omodero, 2019). To make this inquiry more elucidating, the current study employed the autonomous revenue collection of the three levels of government to determine if the country earns sufficient income to alleviate poverty and, if so, what the policy implications should be to address the issue at hand. This new study focused on the necessity for financial discipline to make the greatest use of the resources available to the government. Therefore, *the purpose of this study* was to explore the level of monetary restraint in government, such that will drive poverty control through efficient use of government resources.

LITERATURE REVIEW

X. Cheng et al. (2022) used a one-of-a-kind survey statistic from 3 managerial and 17 regular communities in an impoverished Western China region. The representation directory that considered reciprocity, support time, gift expenditures, and political ties was used to quantify villager social capital. The study demonstrated, using instrumental variable estimates, which villages with strong social capital were more likely to benefit from Targeted Poverty Alleviation (TPA) policies. The findings suggested that village dweller public investment was a major unfavourable source pointing at rural China's decentralised targeting systems, and they also presented new evidence from China that social investment is not a disadvantaged asset. E. Thorbecke & Y. Ouyang (2022) used data from 129 developing nations, 44 of which were in Sub-Saharan Africa, to investigate the reverse causation between poverty and growth from 1981 to 2018. (SSA). The study discovered that quicker poverty reduction is associated with faster growth in the developing world, particularly in the SSA area.

From 2009 to 2019, C.O. Omodero (2021) researched the influence of agricultural productivity and food production on poverty reduction in Nigeria. According to the data, the Food Production Index had a large and positive influence on poverty alleviation, while Agricultural Output had an inconsequential adverse impact on poverty minimisation. E.M. Agri et al. (2020) investigated the influence of government revenue and spending on employment and poverty reduction in Plateau State from 1999 to 2019. The primary goal of this exploration was to examine the influence of government revenue and outlay on employment as well as poverty alleviation in Plateau State. The main findings revealed that government spending on education has a favourable and substantial influence on employment, and that a unit increase will boost employment and lower poverty levels. While agriculture and health had a beneficial link with employment, a little unit increase would diminish work opportunities and raise destitution.

In 116 developing countries, M.A. Omar & K. Inaba (2020) assessed the effect of financial development on poverty and income inequality, as well as the causes and conditional impacts. The research was carried out utilising imbalanced yearly panel data from 2004 to 2016. The study created a novel index of financial incorporation using a broad series of accounting sector outreach metrics, discovering that per capita income, internet user ratio, age dependency ratio, inflation, and income inequality all had a significant impact on the level of financial intermediation in poor economies. Additionally, the findings offered compelling evidence that financial inclusion decreased poverty and income disparity in emerging nations. In Eastern Indonesia, A. Erlando et al. (2020) investigated the role of inclusive growth in accelerating trade and industry progression, alleviating

scarceness, and reducing revenue disparity. The Toda-Yamamoto VAR bivariate causation classical and the self-motivated Square Trajectory Auto-Regression (PVAR) were used in the investigation. The findings during the study period revealed that in Eastern Indonesia, there was a strong link between fiscal annexation, commercial evolution, lack, and affluence dissemination.

Using time series data from 1980 to 2013, N. Chude et al. (2019) explored the link between governments spending, economic development, and poverty reduction in Nigeria, using error correction techniques inside an ARDL framework to get more exact estimations. It had been discovered that government overheads took a productive and weighty sway on commercial progress by raising actual business investment and fixed capital stock, which increased wealth accumulation, reduced the current account deficit and external debt burden, and improved household education and skills by promoting human capital. The study found that government spending had a strong short-run influence on poverty reductions in its lag form, which might be evaluated by the function of financial regulation in reducing widespread poverty. C.O. Omodero (2019) recycled ancillary numbers in investigating sway of management sectors' disbursement on poverty reduction over a millennium period from 2000 to 2017. The commonplace slightest four-sided figure approach was used in the scrutiny, and the regression fallouts specified that government spending on agriculture, building and construction, education, and health had no meaningful influence on poverty reduction in Nigeria.

T. Canare & J.P. Francisco (2019) used data from Philippine cities and municipalities to investigate the link between fragmentation and inequality. The findings revealed that budgetary freedom, as expressed by the percentage of locally derived income to total local government income, was actually related with lower poverty. N. Nursini & Tawakkal (2019) explored panel data regression models for 33 Indonesian provinces from 2010 to 2016. Regional government income and intergovernmental transfers had a statistically significant influence on poverty reduction, but metropolitan state spending could not. The analysis indicated that, in the context of Indonesia's devolution, the rise of regional government income, both from internal sources and from revenue sharing, tended to be much more effective at facilitating poverty alleviation than rise in total regional government spending. T. Sanogo (2019) investigated if and how the decentralisation of revenue-raising tasks to municipalities in Côte d'Ivoire improves access to public services and helps to poverty reduction. According to the findings of this study, higher local revenue improves access to public services and lowers poverty.

E. Anderson et al. (2018) examined the association between government expenditure and income poverty in little and average revenue nations using a meta-regression approach. The study discovered that a variety of factors such as government expenditure, population, and education, among others, influenced the strength and direction of the predicted link. However, T.H. Simanjuntak & I. Muhklis (2017) discovered that financial liberalisation had a considerable impact on poverty as a measure of social fairness. According to H. Sasana (2018), the proportion of total provincial budget as a sign of devolution had a substantial influence on eradicating poverty in Central Java. V.E. Oriavwote & A. Ukawe (2018) studied the bearing of management spending with poverty alleviation in Nigeria. The ECM and co-integration models were used in the study, which spanned the years 1980 to 2016. The Johansen co-integration finding demonstrated the presence of a long run equilibrium connection between the variables. The parsimonious ECM found that, while one-period-lag government spending on health had a considerable and beneficial influence on per capita income, it had low elasticity. The findings also revealed that government spending on education had a considerable and favourable influence on per capita income.

R.S.D. Kusumaningrum (2013) discovered no clear association between revenue mobilisation and poverty alleviation. Furthermore, Maharajabdinul et al. (2015) discovered that transfer funds had no effect on poverty in Eastern Indonesia, while K. Abdillah & D. Mursinto (2016) discovered that province own-source revenues had no influence on local poverty reduction using panel data.

MATERIALS AND METHODS

The study focuses on the use of financial discipline in the allocation of government funds at all levels of government in Nigeria, with the goal of reducing poverty. The independent variables in the research include independent revenues at all levels of government, while the dependent variable is per capita income, which is a good measure of a country's poverty alleviation. The years covered are 2007-2020, and the data for government revenues comes from the Central Bank of Nigeria (CBN) Statistical Bulletin (CBN, 2020), while the data for per capita income comes from the World Bank Development Indicator (WDI, 2020). Log values are employed to ensure numerical consistency. Descriptive statistics are used in the study to determine the nature of the data use and to ensure its normalcy for use. Other diagnostic tests used in this study were the Ramsey RESET Test for stability, the serial correlation test, and tests for normality, multicollinearity, and heteroskedasticity. These tests are required to guarantee that the model meets all of the prerequisites for applicability.

Consequently, the archetypal for this study is detailed below (1):

$$PCI=f(FGFI, SGFI, LGFI) \quad (1)$$

where: *PCI* is the Per Capita Income; *FGFI* is the Federal Government Financial Independence; *SGFI* is the State

Government Financial Independence; *LGFI* is the Local Government Financial Independence.

The econometric form is stated as follows (2):

$$LogPCI_t=\beta_0+\beta_1 LogFGFI_t+\beta_2 LogSGFI_t+\beta_3 LogLGFI_t+\varepsilon \quad (2)$$

where β_0 is the Unbroken; β_1-β_3 are the Relapse factors; ε is the Mistake tenure.

The expected result will be that: β_1-β_3 should exceed the value of zero.

That is, government autonomous income at all levels of government is predicted to have a positive and considerable influence on poverty reduction in the country by increasing the income status of the entire population.

RESULTS AND DISCUSSION

The summary statistics of the current investigation are shown in Table 1. The mean values in Table 1 are greater than the standard deviation, indicating that the dataset has a low dispersion. The Kurtosis values are within acceptable bounds, indicating that the dataset is normal. The Jarque-Bera p-values for all variables are above 5%, indicating customary scattering of datasets.

Table 1. *Summary statistics of the study*

	PCI	LGFI	FGFI	SGFI
Mean	5.656276	1.462248	2.657002	2.794719
Median	5.690997	1.462398	2.708274	2.875630
Maximum	5.874071	1.579784	3.016529	2.903633
Minimum	5.374666	1.322219	2.166537	2.485721
Std. Dev.	0.161688	0.078554	0.238700	0.127248
Skewness	-0.369420	-0.153208	-0.448710	-1.169860
Kurtosis	1.963065	1.973007	2.468142	3.324826
Jarque-Bera	0.945653	0.670020	0.634805	3.254886
Probability	0.623238	0.715331	0.728038	0.196431
Sum	79.18786	20.47147	37.19803	39.12607
Sum Sq. Dev.	0.339857	0.080220	0.740708	0.210498
Observations	14	14	14	14

Source: *author's calculation, 2022*

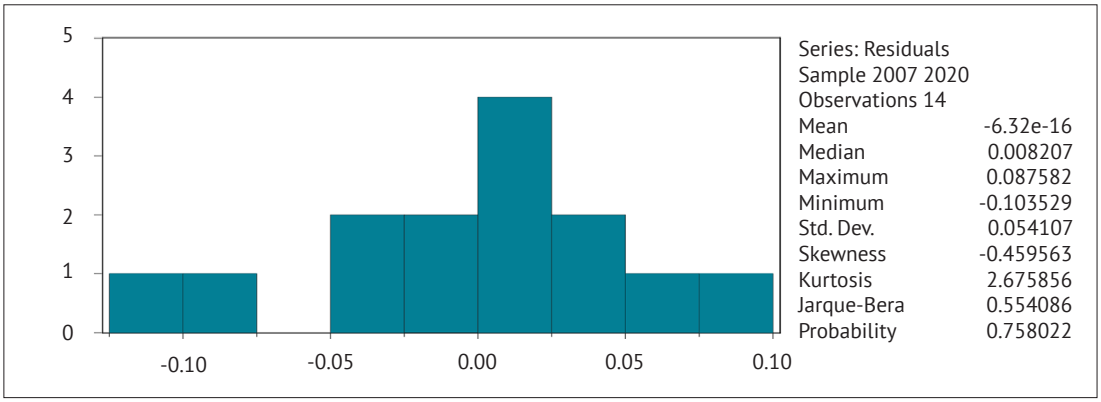

Figure 1. *Histogram normality*

Figure 1 confirms this assertion, whereas Figure 2 confirms model's stability by displaying a green dotted line between two brown dotted lines. Figure 2 is the CUSUM experiment to affirm firmness of the model employed in this investigation. Figure 2 specifies that the CUSUM plot is inside the 5% critical constraint, indicating that the model's parameters did not suffer from structural variability over the research period.

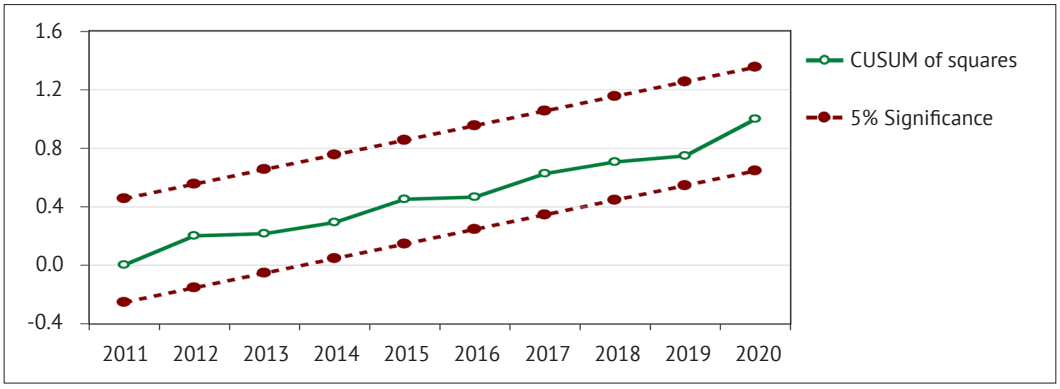

***Figure 2**. CUSUM of squares test*

***Note**: CUSUM=Cumulative Sum Control Chart*

Table 2 contains evidence for several investigative checks that corroborate the model's adoption. The first step is to assess the model's stability; with a p-value of 0.95>0.05, the model is regarded to be stable, as shown in Figure 2. Second, the successive connection assessment assists in deciding whether there is serial correlation. Consecutive correlation arises when a variable and a lagged version of itself (e.g., a variable at times T and T-1) are seen to be associated with one another through time. When the level of a variable affects its future level, repeating patterns often show serial correlation. In statistics, serial correlation is used to explain the relationship between occurrences of the same variable across time. If the serial correlation of a variable is 0, there is no correlation, and each observation is independent from the others. Autocorrelation is the correlation of a signal with a delayed replica of itself as a factor of latency, also known as serial correlation in discrete time. There is no serial association since the probability rate of 0.83 exceeds 5% threshold. Table 2 further proves the absence of multi-collinearity, with all variance inflation factors (VIF) having values less than 10. It is also noted that Heteroskedasticity is missing. As a result, the author's proposed model is acceptable for the research.

***Table 2**. Analytical checks of datasets and model employed for this study*

Kind of problem-solving checks	F-statistics	P-value
Firmness check	0.004	0.95
Successive Connection Test	0.190	0.83
Check of normal distribution of error terms	0.806	0.52
Routine Assessment	0.554	0.76
Check of Interlink among predictor factors	Coefficient variance	VIF
LOGFGIR	0.006	1.232
LOGSGIR	0.040	2.209
LOGLGIR	0.090	1.899

***Source**: author's calculation, 2022*

Table 3 shows the influence of the predictor variable on the response variable, which is a proxy for poverty control. The efficacy of the autonomous resources under the authority of the country's three stages of administration has been investigated to see whether these resources are sufficient to alleviate poverty in the country. The outcome proves that each level of government in Nigeria has sufficient resources to relieve poverty. The federal and state governments create independent revenues that may decrease poverty at the 1% level of materiality, while local governments also generate money that can significantly reduce poverty at the 10% level of confidence. According to Table 3, the link between poverty reduction and government resources at all levels is 94.2% (square root of R-squared). This score is quite high and shows that if government income is efficiently used at all levels of government, poverty in Nigeria can be overcome. Government resources account for 88.8%

of fluctuations in per capita income, and this prediction is error-free based on a standard mistake of reversion of 0.062, less than the value of 1. Based on the Durbin-Watson finding of around 2, there is no autocorrelation in the model. The F-statistic also proves that the approach is adequate and that the autonomous government resources work together to reduce poverty in Nigeria.

***Table 3**. Relapse outcome of test of financial discipline on poverty control*

Factors in log form	Degree	Normal Culpability	t-test	Likelihood rate.
LGFI	.621	.300	2.070522	0.065**
FGFI	.278	.079	3.499002	0.006***
SGFI	.599	.199	2.998475	0.013***
C	2.333	.389	6.003007	0.000
Coefficient of determination	.888	Mean value		5.656
Attuned degree of grit	.854	Standard deviation		.162
Standard mistake of reversion	.062	Akaike information benchmark		- 2.498
Sum shaped residual	.038	Schwarz level		-2.316
Log chances	21.488	Hannan-Quinn yardstick		-2.515
F value	26.433	Measurement of autocorrelation –D/W		2.000
Likelihood of F value measurement	.000			

***Note**: ** Significant at 10%; *** Significant at 1%*
***Source**: author's calculation, 2022*

This finding agrees with the studies of T. Canare & J.P. Francisco (2019) who discovered that fiscal flexibility, as measured by the ratio of domestically sourced revenue to overall regional cash flow in the Philippines, is associated with reduced poverty. The discovery of the present study also corroborates the study outcome of N. Nursini & Tawakkal (2019) which revealed that income from regional governments and intergovernmental transfers had a statistically relevant impact on poverty reduction across the 33 Indonesian provinces. T. Sanogo (2019) also supports the results of this paper by proving that decentralised public revenue enhances poverty alleviation in Côte d'Ivoire municipalities. Other researchers have found that financial liberalisation has a considerable influence on poverty eradication and social fairness (Oriavwote & Ukawe, 2018; Sasana, 2018; Simanjuntak & Muhklis, 2017). Therefore, the findings of this study confirm that if all the levels of government in Nigeria practice financial discipline over government revenues in jurisdiction and under their care, poverty can be eradicated. Since Nigeria is the giant of Africa, there stand to be a multiplier effect on other Sub-Saharan African countries who rely on the economy of this country for survival. Moreso, the mass exodus of persons from Nigeria in search greener pasture in other countries is likely to reduce, if proper economic management by the three strata of government can be strictly practiced.

CONCLUSIONS

Resource management is critical in every country's poverty reduction effort. This research investigates the influence of government-generated income on poverty reduction in Nigeria. According to the findings, the tiers of government in Nigeria have adequate income to eradicate poverty if properly applied. This research shows that Nigeria's problem is not a lack of resources, but a lack of strong leadership at all levels of government. The study recommends that citizens should support leadership with a strong economic management reputation and social welfare as a focus should be allowed to occupy public offices. If the right individuals are in charge, the country's poverty may be effectively handled. Corrupt public officers convicted of stealing from public treasury should face more severe criminal charges. The plunder recovered and its use to improve the well-being of the people should likewise be made public to boost the confidence of the masses in the administration.

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Фінансова дисципліна на всіх рівнях уряду: тест із акцентом на скорочення бідності в Нігерії

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Анотація. У Нігерії нецільове використання державних ресурсів виявилося серйозною проблемою. Хоча жителі країни живуть у бідності, важливо підкреслити, що уряд на всіх рівнях генерує достатні ресурси для викорінення бідності в країні за умови сильного управління та фінансової дисципліни. У цьому дослідженні вивчалася ефективність державних незалежних ресурсів на всіх рівнях у боротьбі з бідністю. Метою дослідження було перевірити вплив незалежних державних ресурсів на скорочення бідності. Дослідження охопило період з 2007 по 2020 роки з використанням вторинної форми даних. Автономний дохід кожного рівня уряду було отримано зі статистичного бюлетеня Центрального банку Нігерії, тоді як дохід на душу населення, що використовується як непрямий показник для боротьби з бідністю, був зібраний з Індикатора розвитку Світового банку. У дослідженні застосовувався метод множинної регресії вивчення впливу державних ресурсів всіх рівнях скорочення бідності Результат регресії показав, кожен рівень уряду генерує ресурси, здатні знизити рівень бідності у Нігерії. Автори роботи рекомендували фінансову дисципліну, сильне управління та економію ресурсів. Це було перше дослідження, в якому вивчалася грошова стеля та використання незалежних ресурсів уряду на всіх рівнях при оцінці ролі, яку уряд може зіграти у зниженні рівня бідності в Нігерії, використовуючи наявні ресурси на кожному рівні влади в країні

Ключові слова: фіскальне обмеження, управління ресурсами, рівні влади, контроль за бідністю

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