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The Influence of the World Grain Market on Prevalence of Mankind's Undernourishment in the Times of War on the Ukraine

Wpływ światowego rynku zbóż na występowanie niedożywienia ludzkości w czasie wojny na Ukrainie

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Abstract

The world cereal production and supply as well as their trade, stock and losses are important indicators of the world market of cereals. They play a huge role in ensuring food security. The aim of this research is to identify the relation of the indicators of the world grain crops market (production, supply, losses, trade, stocks) and the level of malnutrition *Prevalence of Undernourishment* (PoU) among the world's population. Based on data from the Food and Agriculture Organization of the United Nations (FAO), a correlation-regression analysis was conducted between indicators of the global grain crops market, in particular: the wheat market, the fodder market of grain crops, the rice market and PoU of the world population for the period 2013/14 – 2020/2021 marketing years. It has been proven that there is a close, statistically reliable relationship between the above mentioned indicators, except for grain stocks and POU. The analysis of the world cereal market showed that among the indicators characterizing its conditions, the indicator *trade in grain crops* ($r = 0.851$; $D = 0.724$; $F = 3.968$, ($F > F_t$); $z = 1.26$; $rL = 0.37$; $rU = 0.97$) has the highest level of correlation. It was found that with an increase in the volume of world cereal trade by 1 million tons, the PoU level will increase by 0.018%. A review of literary sources proves that the problem of ensuring food security, in particular with regard to reducing the level of starvation and malnutrition, cannot be solved only by fighting climate change, overcoming socio-economic and military problems, fighting pandemics, etc. Its solution to a large extent depends on fair, uniform export and import of food products, as evidenced by the calculations. A separate direction for solving the problem of the spread of malnutrition is the elimination of the policy of highly developed countries regarding the application of individual sanctions against

countries with high PoU values, in particular, the Central African Republic, Madagascar, Haiti, Afghanistan, Chad, Congo, Lesotho, Liberia, Mozambique, etc.

Key words: food security, production, supply, trade, losses, stocks, wheat, fodder cereals, rice, malnutrition, hunger, regression analysis, world grain market, war

Streszczenie

Światowa produkcja i podaż zbóż, a także handel nimi, zapasy i straty są ważnymi wskaźnikami światowego rynku zbóż. Odgrywają ogromną rolę w zapewnieniu bezpieczeństwa żywnościowego. Celem badań jest identyfikacja zależności wskaźników światowego rynku zbóż (produkcja, podaż, straty, handel, zapasy) a poziomem niedożywienia (PoU) wśród ludności świata. Na podstawie danych Organizacji Narodów Zjednoczonych ds. Wyżywienia i Rolnictwa (FAO) przeprowadzono analizę korelacji-regresji pomiędzy wskaźnikami światowego rynku zbóż, w szczególności: rynkiem pszenicy, rynkiem paszowym zbóż, rynkiem rynek ryżu i PoU światowej populacji w latach gospodarczych 2013/14 – 2020/2021. Wykazano, że istnieje ścisła, statystycznie wiarygodna zależność pomiędzy wymienionymi wskaźnikami, z wyjątkiem zapasów zbóż i POU. Analiza światowego rynku zbóż wykazała, że wśród wskaźników charakteryzujących jego warunki znajduje się wskaźnik handlu zbożami ($r = 0,851$; $D = 0,724$; $F = 3,968$, ($F > F t$); $z = 1,26$; $rL = 0,37$; $rU = 0,97$) wykazuje najwyższy poziomem korelacji. Stwierdzono, że wraz ze wzrostem wolumenu światowego handlu zbożami o 1 milion ton poziom PoU wzrośnie o 0,018%. Przegląd źródeł literackich dowodzi, że problemu zapewnienia bezpieczeństwa żywnościowego, w szczególności w zakresie ograniczenia poziomu głodu i niedożywienia, nie można rozwiązać jedynie poprzez walkę ze zmianami klimatycznymi, przezwyciężanie problemów społeczno-gospodarczych i militarnych, walkę z pandemiami itp. Jego rozwiązanie w dużej mierze zależy od sprawiedliwego, jednolitego eksportu i importu produktów spożywczych, co potwierdzają wyliczenia. Odrębnym kierunkiem rozwiązania problemu szerzenia się niedożywienia jest eliminowanie polityki krajów wysoko rozwiniętych w zakresie stosowania indywidualnych sankcji wobec krajów o wysokich wartościach PoU, w szczególności Republiki Środkowoafrykańskiej, Madagaskaru, Haiti, Afganistanu, Czadu, Kongo, Lesotho, Liberii i Mozambiku.

Słowa kluczowe: bezpieczeństwo żywnościowe, produkcja, zaopatrzenie, handel, straty, zapasy, pszenica, zboża pastewne, ryż, niedożywienie, głód, analiza regresji, światowy rynek zbóż, wojna

1. Introduction

Production, distribution, trade, loss and storage of food products are the most important indicators that ensure food security – one of the most important factors connected with sustainable development. Food security is affected by internal and external issues, including climate change, mineral fertilizer shortages, rising energy prices, institutional challenges, global economic crises, inequality, trade wars, geopolitical conflicts, the spread of pandemics, including COVID-19, and wars. The war in Ukraine led not only to a record economic decline over the past 30 years, but also to a decrease in the agricultural production capacity and the food industry of Ukraine, which reduced the supply of grain crops and food products to the world market and exacerbated the problem of PoU in the world (Nasir et al., 2022; (Abay et al., 2022; Bechdol et al., 2022; Bentley et al., 2022; Chikava, 2022). After all, Ukraine can provide about 400 million people with food. These problems have led to the deterioration of the socio-economic development of many countries, the purchasing power of the majority of the world's population, and an increase in the number of starving citizens (Khan et al., 2022; Onyeaka et al., 2022; Nugroho et al., 2021). United Nations Secretary General Antonio Guterres believes that about 60% of the world's undernourished people live in war-torn countries. His thesis sounds: *There is enough food in the world for everyone*, but the main problem is its distribution (United Nations, 2022).

The problem of food shortages is related not only to the above factors, but also to the problems of distribution of produced food in the world (Arita et al., 2022; Montolalu et al., 2022; Wood et al., 2018), accumulation of stocks of food products, high losses of food products (up to 40% in developed countries, in particular up to 20% in the EU countries (Laba et al., 2022; Kozlovskyi et al., 2017; Matviychuk & Velykoivanenko, 2014), present trade barriers and imposed sanctions and other unilateral measures/obstacles, etc.

Therefore, the article proposes to investigate the influence of the world market of grain crops on the level of malnutrition in order to determine the feasible measures to reduce it and increase the level of world food security.

2. Literature review

The World Food Program of the United Nations (UN) was awarded a Nobel Peace Prize in 2020 for fighting hunger and its prevention as a weapon of war and military conflicts (Sajid, 2021). According to UN data (Center for Strategic and International Studies, 2022), in 2020, about 3.1 billion people in the world could not afford the cheapest form of healthy food, the cost of which is estimated by experts to be roughly $3.54. USA per day. These

data are without the full impact of the COVID-19 pandemic and the war in Ukraine. Although trade in agricultural products remained somewhat stable amid the spread of the COVID-19 pandemic, the global agricultural sector remained relatively stable. COVID-19 reduced agricultural trade by 5–10% at the aggregate level of the agricultural sector, while trade in the non-agricultural sector fell two to three times more (Arita et al., 2022). The war in Ukraine proves to have led to significant material losses on both warring sides, which had an extremely strong impact on food security. This caused a disruption in the global food export and trade chain (Nasir et al., 2022), in particular grain crops, and threatens the spread of hunger and malnutrition among a larger part of humanity (Khan et al., 2022). Thus, Fig. 1 shows the production of wheat in Ukraine in 2018−2022.

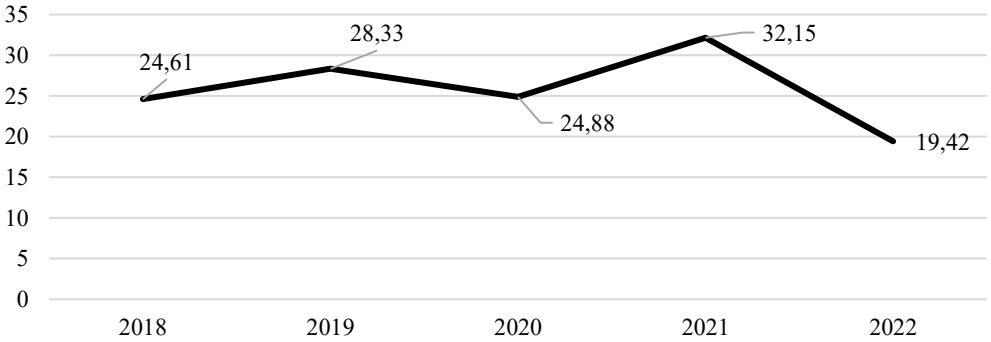

Figure 1. Volumes of wheat production in Ukraine in 2018−2022, with the exception of the occupied territories in Ukraine (APK Inform, 2022)

The information in Fig. 1 shows that the volume of wheat production in Ukraine in 2022 decreased by 21% or by 5.19 million tons as compared to 2018. The main reason for the drop of wheat production is the reduction of the farm lands for the corresponding period by 40.13% due to the occupation of territories and infeasibility of farming as a result of mining, contamination by projectiles and the conduct of active hostilities. The war has also affected exports, which in 2022/23 compared to 2021/22 marketing years decreased by 3.18 times or by 3237 thousand tons. For example, wheat exports to Indonesia decreased by 16.45 times, to Egypt by 10.50 times, to Bangladesh by 2.20 times, and Turkey increased its imports from Ukraine by 12.28% to 1426 thousand tons in the corresponding period. Turkey took the first place in the export of Ukrainian wheat, followed by: Romania - 1163; Spain – 808; Poland – 439; Italy – 346; Bangladesh – 288; Liberia – 229; Nigeria – 211; Egypt - 206; Indonesia - 161; other countries of the world - 1488 thousand tons.

As a result, world wheat prices are likely to rise by up to 9% and increase the number of undernourished people in the world to 13 million (Bechdol et al., 2022). After all, the two belligerent countries account for about a third of world wheat exports (Mottaleb, K., & Govindan, 2023). Disruption of cereal exports will especially create food shortages in regions (Largerly Middle East and North Africa) depending on exports from Ukraine, in particular (Abay et al., 2022). The problem of PoU, for example, in Africa is determined not only by these objective factors, but also with such a subjective factor as - significant volumes of informal trade in food products, which negatively affects the uniformity of providing citizens with food products (Onyeaka et al, 2022). For instance, malnutrition spread in Indonesia, is particularly related to the policy of social restriction, which causes problems with food products distribution and their price growth (Nugroho et al, 2021).

The study proves (Mottaled, 2022) that a 1% decrease in the average world wheat trade can lead to a 1.1% increase in the producer wheat price, and a 1% increase in the producer wheat price of wheat can reduce the annual wheat consumption by 0 .59% per capita. Besides, reduction in wheat exports from Russia and Ukraine by 50% may lead to a 15% increase in the price of wheat producers, which will lead to a reduction in wheat consumption by at least 8%. Export restrictions affect global food security and lead to negative consequences for consumers and farmers (Zhai, 2022).

Inequality in the provision of food products is a key problem of ensuring food security and reducing the prevalence of malnutrition. The literature emphasizes that the amount of world food products nowadays is enough to feed all the humanity. The problem lies not in insufficient food production but in inequality, that threatens food security (D'Odorico et al, 2014). Currently, there is a lot of discussion about the need to reduce the consumption of food products. Due to the spread of hunger and malnutrition in the world, this path is not rational (Duro et al., 2018). Therefore, today instead of the policy of reducing food consumption, it is necessary to implement strategies on reducing discrepancy between food production and consumption in the whole world (Duro et al., 2018 ; Schaffartzik et al., 2019) and food losses.

Food losses begin with primary production and end with storage, processing, distribution and consumption. For example, in Poland, the level of loss of grain crops per farm is 0.91 tons or 1.7% of the total volume of production (Laba et al, 2022). Approximately 60% of grain crops can be lost at the storage stage, in particular due to lack of

technical capabilities. About a third of the food produced (about 1.3 billion tons) worth about 1 trillion dollars USA is lost annually after harvest (Kumar, 2017).
Further studies conclude that the divergence in food consumption among countries is changing on a global scale, and the problems of inequal access not only to food products in certain countries, but also their distribution within countries, are becoming increasingly important (D'Odorico et al, 2019).
Solving food security problems requires a quantitative and qualitative increase in the production and export of grain crops and other types of food. Thus, according to A. Duro et al. (2020) it is necessary to increase food supply in the Global North while reducing excessive consumption in other regions of the world, particularly in the industrialized North. A noticeable increase in the food index is observed in the countries with the lowest and middle incomes, but it does not decrease in the developed countries of the world (in high income countries) (Lavrov et al., 2022). Thus, the research proves that the lowest growth of the food index is recorded in the group of countries with low incomes. In other words, poor countries will remain so for a long period of time, unless the situation with inequality between low- and high-income regions change. At the same time, an important conclusion was made that the inequality associated with the food index can be reduced by optimizing the resource consumption model of the richest countries (Kozlovskyi et al., 2018; Gerasymenko et al., 2010).
The problem of the malnutrition spread and hunger is connected not only with insufficient volumes of export, import, and trade, but also with import of non-essential products (strawberries, exotic fruits and vegetables) by developed countries, which consumes enormous resources (Kozlovskyi, 2010). Excessive meat production, mainly for the wealthy part of the population, requires huge amounts of feed grain, which could be sent to poor countries and save about 30 million people from malnutrition and hunger every year (Trade and Food Production System, 2021).
Trade, import and export are, undoubtfully, part of any economic development. At the same time, if it does not lead to dependence, in particular to a negative trade balance. In addition, food imports, on which millions of people depend, under certain conditions, can be a powerful *weapon* in the hands of highly developed and rich countries (Alternatives to Food Import Dependency, 2013). Developed countries, primarily the G8 countries, see Africa as a promising market for land, food and biofuel. For example, the ProSavanna project in Mozambique resulted in farmers being forced to abandon their land and their livelihoods. TNCs such as Yara, Monsanto, Syngenta, Cargill seek to privatize African agriculture and put corporate profits above food security (African groups reject G8 corporate food plans as *colonialism*, 2013).
A review of the literature on the problem of the impact of production, trade, stocks and other indicators that characterize the world market of grain crops allowed us to conclude that the majority of world scientists focus their research on the problem of human malnutrition related to purely objective factors. First of all, it is the climate change, socio-economic and political dangers, including revolutions, strikes, wars, etc. Little attention has been paid to subjective factors, in particular, the unfair and uneven distribution of food products between countries, the introduction of sanctions by developed countries, in particular, the circumvention of international norms stipulated by the UN. That is why the article proposes to conduct an analysis of the existence of a connection between the indicators that characterize the development of the world market of grain crops (production, supply, losses, stocks, trade) and their impact on the level of malnutrition of the world population.

3. Methodology

The study involves the following stages: analysis of the prevalence of undernourishment (PoU) of the world's population, in particular for individual countries of the world, which have a POU level > 2.5%; calculation of rates of growth (decrease) in the level of PoU in 2020 compared to 2001 in countries of the world with a level of PoU > 2.5%; calculation of the rates of growth (decrease) in the global volumes of production and sale of grain crops (for the period 2013/14 – 2022/23); carrying out a correlation-regression analysis in order to study the influence of indicators of the world market of grain crops (production, supply, losses, trade, stocks) on the level of PoU .
The statistical database of the Food and Agriculture Organization of the United Nations (Food and Agriculture Organization of the United Nations, FAO) was used for the relevant analysis.
FAO, within the framework of the implementation of the Sustainable Development Goals, proposed to study the indicator *prevalence of undernourishment* (*Prevalence of Undernourishment*, PoU). This indicator represents the specific weight of the population, whose usual food consumption is insufficient to ensure the necessary level of energy in the general structure of the population, to maintain a normal active and healthy life.
The calculation of the PoU indicator is based on the probability distribution of the usual daily level of caloric intake of an *average* individual and is modeled by a parametric probability density function (f(x)). Once the parametric function f(x) is characterized, the PoU indicator is calculated as the integral probability that the daily habitual levels of caloric intake (x) are below the lower limit of the range of normal caloric intake for this representative or average individual (MDER) (formula 1)

$$PU = \int\_(x < MDER)\ f(x \mid DEC; CV; Skew)\ dx \quad (1)$$

where PU is the *prevalence of malnutrition* indicator, %;

MDER - minimum caloric content of the food ration, kcal;
f(x) is a parametric function of the probability density of parameters (DEC, CV, Skew);
DEC – the average value of the distribution of calorie consumption levels, kcal;
CV – coefficient of variation of normal food consumption by the population;
Skew is an asymmetry that is estimated directly from data on average daily calorie consumption at the household level (provided that extreme high and low values are excluded).
The information basis for calculating the PoU indicator is a survey of households regarding their food consumption, in particular, FAO uses data on the demographic structure of the population (by gender, by age); data on citizens' the physical features (average weight, height and age); data on physical activity levels among the population; data on the total amount of available and consumed food. Simultaneously, the statistics of the UN world population division prospects are used; structures of the national population by gender, age (every two years) for the vast majority of countries in the world; food balances of the FAO, which contain information on available food to the population; household survey statistics by national statistical agencies (through special bilateral agreements) on food consumption, etc.
The world cereal market can be characterized by the following indicators: production, supply, losses, trade, stocks at the end of the period (FAO, World Food Situation). The data related to the *production (offer)* indicator are characterized by the volume of global cereal production, in particular wheat, feed grain crops, and rice. The *supply (demand)* indicator includes the global supply of grain crops. The *trade* index is formed according to statistical data on exports in the buying season of June/July for wheat and fodder cereal and exports in the buying season of January/December for rice. The *from stocks* indicator is defined as the difference between the world volumes of supply and the world volumes of consumption (demand) of grain crops, but it may not be equal to this difference due to differences between calculation periods in the implementation system, which are adopted in different countries. The *loss* index reflects the world's disposal of grain crops that, due to various factors, have become unfit for food and animal feed.
The influence of indicators that characterize the world cereal market (x) (production, supply, trade, losses, stocks) on the level of mankind's undernourishment (Y) is determined by the correlation-regression analysis, which involves the construction of a correlation equation (formula 2): (Chatterjee et al, 2013; Ilyash et al, 2020):

$$Y_x = a_0 + a_1 x, \tag{2}$$

where Y_x is a linear equation;
and $_0$ and $_1$ are parameters (coefficients) of the equation;
x is the influence factor.

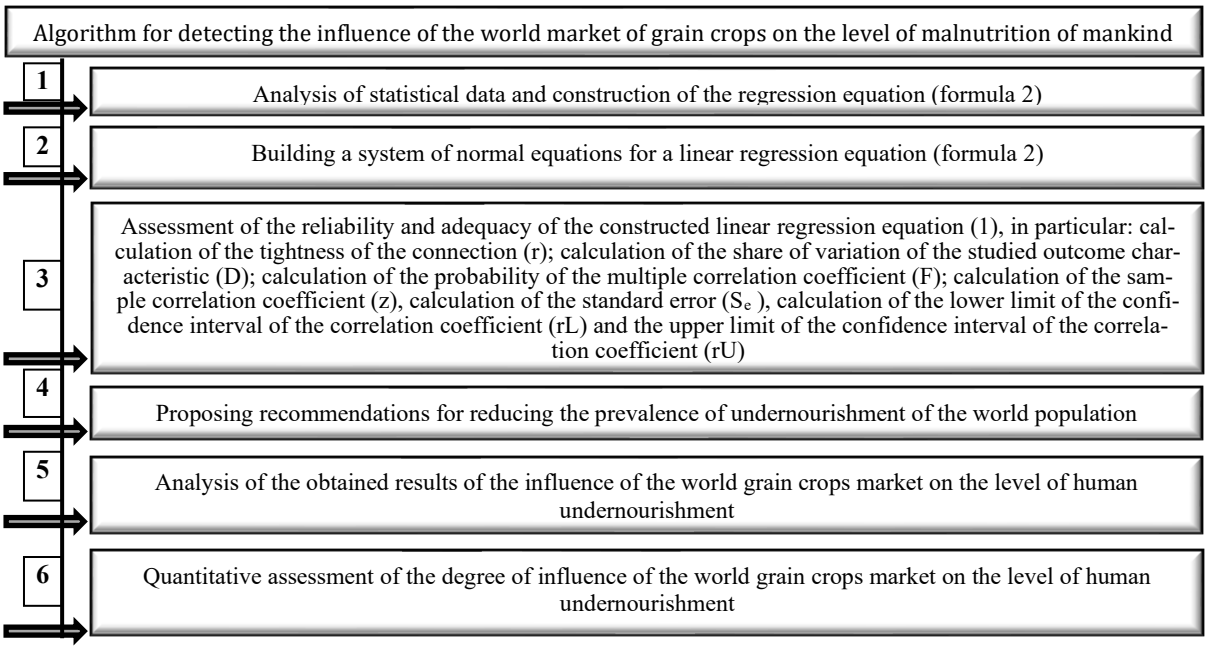

Figure 2. Algorithm for detecting the influence of the world market of grain crops on the level of mankind's undernourishment (author's development)

The unknown parameters of the regression equation (a_0, a_1) are proposed to be found by the method of least squares. For this, a system of normal equations is built. The closeness of the relationship is estimated using the linear correlation coefficient. The share of the variation of the studied result characteristic (Y) is caused by the influence of the factors (x) included in Regression equation 1and is determined by the determination coefficient

(D). It is proposed to estimate the probability of the multiple correlation coefficient (as well as the correlation equation in general) by calculating the F-criterion (F). In addition to the closeness of the relationship, the following indicators are used to assess the adequacy of the regression equation (2) for real processes: sample correlation coefficient (z), standard error (S_e), the lower limit of the confidence interval of the correlation coefficient (rL), the upper limit of the confidence interval of the correlation coefficient (rU). The algorithm for detecting the influence of the world market of grain crops on the level of malnutrition of humanity is shown in fig. 2.
The reliability and adequacy of the constructed linear regression equation (formula 1) was assessed using the PoU Excel program, the appropriate functions from the statistical package of the PoU Excel program were used to calculate the F-criterion and determine its tabular value.

4. Results and discussion

In this section of the article, an analysis of the prevalence of undernourishment (PoU) of the population in the world is carried out, in particular for certain countries, which have a PoU level > 2.5%; the rate of growth (decrease) of the PoU level in 2020 compared to 2001 in countries of the world with a PoU level > 2.5% was calculated; the rates of growth (decrease) in the global cereal production and sale (for the period 2013/14 – 2022/23) were calculated; a correlation-regression analysis was carried out in order to study the influence of indicators of the world market of grain crops (production, supply, losses, trade, stocks) on the level of PoU.

4.1. Analysis of the prevalence of undernourishment (PU) and changes in production and sales in the world cereal market

According to FAO data, the level of PoU during 2000–2020 had a positive downward trend, which is clearly visible from fig 3.

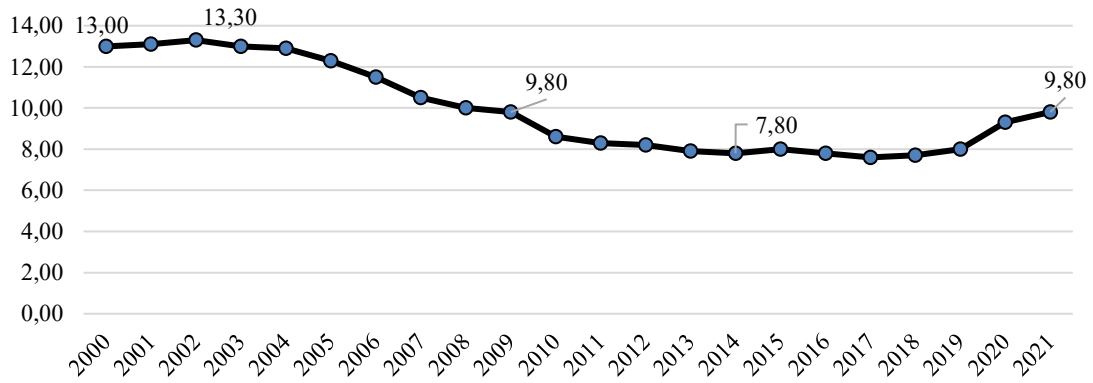

Figure 3. PoU level in 2000-2020 [the level of people who undernourishment in the total population] (FAO, 2022)

Thus, during the period 2000–2020, the PoU level decreased by 3.7 percentage points or by 28.47%. In 2021, compared to 2020, the PoU level began to grow by 0.5 percentage points equal to 5.38%. An increase in the PoU level in 2021 compared to 2000 indicates a worsening food problem and means the prospective undernourishment growth. The main reasons for this, according to the literature review, are, in particular: the spread of the COVID-19 pandemic, climate change, aggravation of socio-economic and political problems, in particular, the war conflicts in many countries. At the same time, the level of PoU in each country depends, first of all, on its socio-economic condition, the model of economic development, etc. Table 1 shows the level of PU in 2020 by individual countries of the world (FAO).
Among the above mentioned countries (see table 1) the highest PoU level in 2020 is detected in Somali and the Central African Republic (53,1% and 52,2% respectively), proving that every second their citizen is undernourished. Similar situation is typical of the countries: Madagascar – 48,5%, Haiti – 47,2%. Every third citizen of the Afghanistan – 29,8%, Chad – 32,7%, Kongo – 31,6%, Lesotho – 34,7%, Liberia – 38,3%, Mozambique – 32,7% suffers from malnutrition. The lowest PoU levels (PoU < 2,5%) in 2020 are also registered in: Azerbaijan, Australia, Austria, Australia and New Zealand, Belgium, Bosnia and Herzegovina, Belarus, Canada, China, Cuba, Czech, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Kazakhstan, Republic of Korea, Latvia, Lithuania, Luxembourg, Malaysia, Malta, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Slovenia, Sweden, Switzerland, Turkey, Ukraine, The United Kingdom of Great Britain and Northern Ireland, The United States, The Virgin Islands and Uzbekistan. Table 2 shows the calculation of the PoU growth (decrease) pace in 2021 compared to 2001 (FAO).

Table 1. The level of PU in 2020 by individual countries of the world (FAO, 2020)

Country	PU level	Country	PU level	Country	PU level	Country	PU level
Afghanistan	29,8	Brazil	4,1	Gabon	17,2	Jordan	16,9
Albania	3,9	Belize	7,4	Georgia	7,6	Kenya	26,9
Angola	20,8	Solomon Islands	18,1	Gambia	21,6	Lesotho	34,7
Argentina	3,7	Bulgaria	3	Guatemala	16	Liberia	38,3
Bangladesh	11,4	Cameroon	6,7	Haiti	47,2	Madagascar	48,5
Armenia	3,5	Central African Rep.	52,2	Honduras	15,3	Mali	9,8
Barbados	3,4	Chad	32,7	India	16,3	Mexico	6,1
Melanesia	19,7	Colombia	8,2	Indonesia	6,5	Mozambique	32,7
Polynesia	4,1	Congo	31,6	Iran	4,1	Oman	9,8
Central and Southern Asia	16,4	Ecuador	15,4	Iraq	15,9	Namibia	18
Bolivia	13,9	Ethiopia	24,9	Côte d'Ivoire	4,4	Nepal	5,5
Botswana	21,9	Djibouti	13,5	Japan	3,2	Somalia	53,1

Table 2. The pace of PoU growth (decrease) in 2020 compared to 2001 (FAO, 2020)

Country	PoU level	Country	PoU level	country	PoU level	country	PoU level
Afghanistan	63,35	Brazil	38,32	Gabon	160,75	Jordan	174,23
Albania	79,60	Belize	127,59	Georgia	98,71	Kenya	83,54
Angola	30,82	Solomon Islands	136,09	Gambia	121,35	Lesotho	173,5
Argentina	123,34	Bulgaria	75,0	Guatemala	72,08	Liberia	104,65
Bangladesh	71,70	Cameroon	106,35	Haiti	93,10	Madagascar	143,5
Armenia	13,41	Central African Rep.	133,17	Honduras	69,87	Mali	60,50
Barbados	53,13	Chad	84,28	India	88,59	Mexico	184,85
Melanesia	88,74	Colombia	94,26	Indonesia	33,86	Mozambique	89,59
Polynesia	113,16	Congo	117,04	Iran	85,42	Oman	79,68
Central and South-ern Asia	90,11	Ecuador	73,34	Iraq	71,95	Namibia	133,34
Bolivia	49,82	Ethiopia	52,98	Côte d'Ivoire	21,57	Nepal	23,41
Botswana	92,41	Djibouti	32,15	Japan	128,1	Somalia	75,22

The biggest progress towards the reduction of PoU level in 2020 comparing to 2001 was detected in the following countries (table 2): Angola – 30,82%; Brazil – 38,3 2%, Indonesia – 33,86%, Côte d'Ivoire – 21,57%, Nepal – 23,41%. The highest PoU growth in 2020 comparing to 2001 was registered in Mexico – 184,85%, Lesotho – 173,5%, Jordan – 174,23%, Gabon – 160,75%, the Central African Republic – 133,17%, Beles – 127,59%. Table 3 shows the pace of growth (decrease) of the world cereal production and sale, in particular wheat market, forage grain and rice markets (FAO).

Table 3. The pace of growth (decrease) of the world volume of cereal production and sale, from 2013/14 to 2022/23 (FAO, 2020)

Period	World grain market, %		in particular:					
			Wheat market, %		forage grain market, %		rice market, %	
	Production	Supply	Production	Supply	Production	Supply	Production	Supply
2014/15–2013/14	101,98	104,11	102,84	103,86	102,28	105,36	99,92	101,41
2015/16–2014/15	99,10	102,26	100,22	103,25	98,29	102,54	99,70	100,17
2016/17–2015/16	103,12	103,06	103,55	104,20	103,41	103,25	101,66	100,91
2017/18 –2016/17	101,06	101,82	99,76	102,15	101,95	102,12	100,56	100,51
2018/19–2017/18	98,20	99,52	96,04	99,31	98,14	98,85	101,66	101,68
2019/20–2018/19	102,60	101,29	103,86	101,32	103,21	101,48	99,10	100,74
2020/21–2019/20	102,32	101,66	102,03	102,51	102,29	100,98	102,85	102,20
2021/22–2020/21	101,23	101,18	100,37	101,03	101,68	101,02	101,24	101,85
2022/23–2021/22	98,67	99,46	102,14	101,66	96,94	98,30	98,52	99,19

The pace of growth (decrease) of the world volumes of grain production and sale for the period 2013/14 – 2022/23 is instable (table 3). Thus, the world grain market did not show any changes at this period, while the highest growth pace was registered 2016/17–2015/16 – 103,12% and 2019/20–2018/19 – 102,6%. In 2022/23 – 2021−22 there

was a decrease of production with – 98,67%. Similar trends are noticed at the forage grain and rice markets. as for wheat production in the world market, there was growth by 2,14%. There were no significant changes in the grain market in 2013/14 – 2022/23.

4.2. The influence of the world grain market indicators on the PoU level

For the purpose of studying the influence of the world grain market indicators on the PoU level we applied correlation-regressive analysis building regression equations (formula 1). The output data for the regression equations and evaluation of their parameters are shown in Table 4. The built regression equations and evaluation of their parameters are shown in Table 5.

Table 4. Output data for studying the impact of world grain market indices (x) on PoU level (Y) (FAO, 2020)

Period	Y, %	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
		million tons									
2013/14	7,80	2 608,0	3 278,3	2 508,1	376,0	768,0	735,6	935,0	708,6	156,4	228,1
2014/15	8,00	2 584,5	3 352,4	2 553,1	393,1	789,9	737,3	965,4	717,1	167,5	242,5
2015/16	7,80	2 665,0	3 454,9	2 631,2	407,0	824,2	763,4	1 005,9	737,9	177,2	265,9
2016/17	7,60	2 693,4	3 517,6	2 658,3	423,0	856,0	761,6	1 027,5	738,1	177,9	288,9
2017/18	7,70	2 644,9	3 500,9	2 685,8	411,9	832,2	731,4	1 020,3	749,6	169,1	274,1
2018/19	8,00	2 713,7	3 545,9	2 710,6	439,5	828,1	759,7	1 033,8	747,5	183,7	284,6
2019/20	9,30	2 776,8	3 604,9	2 759,6	480,5	836,5	775,1	1 059,8	761,9	189,4	292,7
2020/21	9,80	2 811,0	3 647,6	2 797,9	482,1	854,2	778,0	1 070,7	773,0	195,7	293,8
2021/22	7,80	2 608,0	3 278,3	2 508,1	376,0	768,0	735,6	935,0	708,6	156,4	228,1
2022/23	8,00	2 584,5	3 352,4	2 553,1	393,1	789,9	737,3	965,4	717,1	167,5	242,5
2013/14	7,80	1 382,0	1 680,0	1 313,1	174,6	364,3	490,4	663,3	486,5	45,0	175,5
2014/15	8,00	1 358,3	1 722,6	1 345,0	184,2	374,0	489,0	664,5	490,9	41,3	173,4
2015/16	7,80	1 404,5	1 778,5	1 398,1	181,5	384,3	497,1	670,5	495,2	48,3	174,1
2016/17	7,60	1 432,0	1 816,2	1 422,1	196,7	390,0	499,9	673,9	498,0	48,5	177,1
2017/18	7,70	1 405,3	1 795,3	1 435,1	198,5	371,4	508,1	685,2	501,1	44,3	186,7
2018/19	8,00	1 450,5	1 821,8	1 462,0	210,0	356,0	503,6	690,3	501,2	45,8	187,5
2019/20	9,30	1 483,7	1 839,7	1 487,6	238,9	349,8	517,9	705,4	510,1	52,2	194,1
2020/21	9,80	1 508,7	1 858,4	1 503,5	230,5	364,4	524,4	718,5	521,4	55,8	196,0
2021/22	7,80	1 382,0	1 680,0	1 313,1	174,6	364,3	490,4	663,3	486,5	45,0	175,5
2022/23	8,00	1 358,3	1 722,6	1 345,0	184,2	374,0	489,0	664,5	490,9	41,3	173,4

where: x_1 – world grain production; x_2 – world grain supply; x_3 – world grain crop losses; x_4 – world grain trade volumes; x_5 – world grain stock; x_6 – world wheat production; x_7 – world wheat supply; x_8 – world wheat losses; x_9 – world wheat trade volumes; x_{10} – world wheat stock; x_{11} – world grain production for forage; x_{12} – world supply of grains for forage; x_{13} – world losses of grains for forage; x_{14} – world trade of grains for forage; x_{15} – world stock of grains for forage; x_{16} – world rice production; x_{17} – world rice supply; x_{18} – world rice losses; x_{19} – world rice trade volumes; x_{20} – world rice stock.

Table 5. Influence of the world grain market indices (x) on the PoU level (Y) (author's development)

Factors of influence	r	D	F	F_t	z	S_e	rL	rU	Regression equation
x_1	0,816	0,666	3,454	2,447	1,14	0,45	0,26	0,97	$Y = - 14,753503 + 0,008561x_1$
x_2	0,662	0,438	2,164		0,80		-0,08	0,93	$Y = - 7,153391 + 0,004416x_2$
x_3	0,707	0,499	2,450		0,88		0,01	0,94	$Y = - 7,576042 + 0,005943x_3$
x_4	0,851	0,724	3,968		1,26		0,37	0,97	$Y = 0,501405 + 0,018162x_4$
x_5	0,382	0,146	1,015		0,40		-0,44	0,86	$Y = - 0,299830 + 0,010381x_5$
x_6	0,702	0,493	2,414		0,87		-0,01	0,94	$Y = - 15,781887 + 0,031819x_6$
x_7	0,645	0,416	2,069		0,77		-0,11	0,93	$Y = - 3,578820 + 0,011657x_7$
x_8	0,719	0,517	2,540		0,91		0,03	0,95	$Y = - 12,298356 + 0,027704x_8$
x_9	0,759	0,576	2,862		1,00		0,12	0,95	$Y = - 0,500258 + 0,049403x_9$
x_{10}	0,496	0,246	1,399		0,54		-0,32	0,89	$Y = 3,709730 + 0,016734x_{10}$
x_{11}	0,801	0,642	3,312		1,11		0,23	0,96	$Y = - 10,329557 + 0,013010x_{11}$
x_{12}	0,578	0,334	1,733		0,66		-0,21	0,91	$Y = - 5,828891 + 0,007869x_{12}$
x_{13}	0,668	0,446	2,200		0,81		-0,07	0,93	$Y = - 3,502175 + 0,008271x_{13}$
x_{14}	0,840	0,706	3,781		1,22		0,33	0,97	$Y = 2,231382 + 0,029816x_{14}$
x_{15}	-0,580	0,336	1,726		-0,66		-0,91	0,22	$Y = 21,194167 - 0,035055x_{15}$
x_{16}	0,825	0,681	3,570		1,17		0,29	0,97	$Y = -19,055262 + 0,054200x_{16}$
x_{17}	0,874	0,764	4,394		1,35		0,44	0,98	$Y = - 16,469853 + 0,036142x_{17}$
x_{18}	0,858	0,736	4,096		1,29		0,39	0,97	$Y = - 23,895250 + 0,064220x_{18}$
x_{19}	0,811	0,658	3,396		1,13		0,25	0,96	$Y = 1,377467 + 0,1444199x_{19}$
x_{20}	0,798	0,637	3,253		1,10		0,22	0,96	$Y = - 4,907031 + 0,071871x_{20}$

The level of PoU is ambiguously dependent on the indices of the world grain market (production, supply, trade, losses and stock). The greatest dependence (under other equal conditions) was on the following indices: x_4 – trade (grains). The built correlation-regression equation is characterized by the following parameters: r = 0,851; D = 0,724; Fisher's coefficient (F = 3,968) of more normative value (F_t = 2,447), i.e. ($F > F_t$), z = 1,26; rL = 0,37; rU = 0,97; x_1 – production (grain crops) respectively (r = 0,816; D = 0,666; Fisher's coefficient (F = 3,454) above the normative (table) value (F_t = 2,447), i.e. ($F > F_t$), z = 1,14; rL = 0,26; rU = 0,97); x_3 – losses (grain crops) (r = 0,707; D = 0,666; Fisher's coefficient (F = 2,450) ($F > F_t$), z = 0,88; rL = 0,01; rU = 0,94). Although indices x_2 – «supply» and x_5 – «stock» have a certain impact on PoU, but the regression equations are not statistically adequate and reliable. The index x_4 – «trade» among other values at the world grain market (other things being equal) has a significant impact on PoU. Thus, 72,42% of world grain trade volume influence the PoU level, while the other 27,58% are influenced by other factors. The constructed correlation-regression equation proves that the indicated influence is positive and directly proportional. That is, with an increase in trade volumes by 1 million tons, the PoU level will increase by 0.018%. Accordingly, with an increase in world grain production by 1 million tons, the PoU level will increase by 0.008%.

Indicators of the world wheat market as part of the world grain market have the following influence: the indicator x9 - *trade* (wheat) has the greatest influence on PoU (other things being equal) (Karyy et al., 2022). The received correlation-regression equation is characterized by the following parameters: r = 0.759; D = 0.576; Fisher's coefficient (F = 2.862) (F > Ft), z = 1; rL = 0.12; rU = 0.95. With an increase in world wheat trade volumes by 1 million tons, the PU level will increase by 0.049%. Indicators of the world feed grain market (x11 - x15) (other things being equal) have a sufficiently high level of influence on PoU, but the constructed correlation-regression equations based on indicators x12 - x13, x15 are not statistically reliable and adequate. Indicator x_{14} «trade» (feed grain) has a noticable influence on PoU (other things being equal). The correlation-regression equation has the following parameters: r = 0,840; D = 0,706; Fisher's coefficient (F = 3,781) ($F > F_t$), z = 1,22; rL = 0,33; rU = 0,97. With an increase in world trade in feed grains by 1 million tons, the PU level will increase by 0.029%.

The highest levels of influence according to the above indicators (other things being equal) (x16 - x20) are recorded on the global rice market. All constructed correlation-regression equations are characterized by statistical reliability and adequacy. Thus, the highest level of influence on PoU was recorded according to indicator x17 - *supply* (of rice) (other things being equal). The constructed correlation-regression equation is characterized by the following parameters: r = 0.874; D = 0.764; Fisher coefficient (F = 4.394) (F > Ft), z = 1.35; rL = 0.44; rU = 0.98. For example, the amount of rice supplied to the global grain market affects the PoU level by 76.4%, and other factors influence the remaining 23.6%. With an increase in global rice supply by 1 million tons, the PoU level will increase by 0.029%. The next indicator that has one of the highest levels of influence on PoU is the indicator x18 - *losses* (of rice) (other things being equal). The constructed correlation-regression equation is characterized by the following parameters: r = 0.858; D = 0.736; Fisher coefficient (F = 4.096) (F > Ft), z = 1.29; rL = 0.39; rU = 0.97. Thus, 73.6% (all other things being equal) of rice losses on the world grain market affect the PoU level, and the remaining 26.4% are influenced by other factors. With an increase in global rice losses by 1 million tons, the PoU level will increase by 0.064%.

The constructed correlation-regression equation for the index x16 – *production* of rice (other things being equal) is characterized by the following parameters: r = 0.825; D = 0.681; Fisher coefficient (F = 3.570) (F > Ft), z = 1.17; rL = 0.29; rU = 0.97). Thus, 67.1% (all other things being equal) of the volume of rice production on the world grain market affects the level of PU, and the remaining 32.9% is influenced by other factors. With an increase in global rice losses by 1 million tons, the PU level will increase by 0.054%.

4.3. Findings

Having conducted research into the situation with the prevalence of malnutrition in the world, in particular in the countries of the world where PoU > 2.5, it can be concluded that the situation has worsened over the past two years. The level of PoU in the world began to increase, in particular due to climate change on Earth, the spread of the COVID-19 pandemic and the worsening of socio-economic and political problems in the world (Sajid, 2021; Arita et al., 2022; Nasir et al., 2022; Khan et al., 2022; Poliakov, R., & Zayukov, I., 2022; Poliakov, R., & Zayukov, I., 2023 and others). An important trend in curbing and reducing the PoU level is promoting world grain production, especially wheat and rice. This induced the research into the relation of the world grain market indices and the PoU level.

The scientists propose the solution of the problem of PoU as the factor of food security by quantitative and qualitative production and export increase of grains and other foods (A. Duro et al.,2020 та багатьох інших). However, the search in the Scopus data base for the dependence of the PoU level on the world grain market by the indices: production, supply, trade, losses and stock did not give desired information. There is plentiful research into the dependence of production grain prices on the world grain trade (Mottaled, 2022; Zhai, 2022 та багато інших); the price growth and the annual grain consumption per capita (Mottaled, 2022) and others. Unfortunately, there is no research testifying the relation between the indices characterizing the development of the world grain market and the PoU level.

The article presents a correlation-regression analysis of the influence of the world market of grain crops on the level of human undernourishment, which showed that the increase in the volume of production, supply, trade, and stocks of grain crops does not clearly affect the decrease in the level of PoU. For instance, provided the world grain production increases in the marketing year 2023/24 by 5% (from 2811,0 million tons to 2951,55 million tons), the use of the proposed in the article regression models will show the growth of PoU from 9,8% to 10,51% or i.e. by 0,71 percentage point. Thus, with the growth of the world grain production the level of PoU will grow. Under a similar hypothetical condition, according to the indicator characterizing the global grain market - *supply*, the situation is the opposite, but only under the condition of growth of no more than 5%, while with higher values, the situation according to the indicator *production* will be similar. With the growth of the world cereal supply from 3647.6 million tons to 3829.98 million tons the PU level will decrease in the 2023/24 marketing year by 0.04 percentage points and may amount to 9.76%. The situation is similar for the *trade* indicator. With the growth of world trade in grain crops from 482.1 million tons to 506.20 million tons the PU level will decrease in the 2023/24 marketing year by 0.18 percentage points and may amount to 9.70%. The growth of global grain crops losses from 2797.9 million tons to 2937.79 million tons, the will cause the increase of PoU in the 2023/24 marketing year by 0.08 percentage points and may amount to 9.88%, but the reduction of the corresponding losses by 5% will lead to the decrease of PoU by 1.66 percentage points. According to the *stocks* indicator, the increase in the global stocks of grain crops from 854.2 million tons to 896.919 million tons will also lead to the reduction of the PoU in the 2023/24 marketing year by 0.87 percentage points and may amount to 9.01%. Thus, the most rational way of reducing PoU is the reduction of the world losses of grain/cereal crops (Laba et al, 2022; Kumar, 2017) and extension of their trade volumes (import and export).

For the purpose of reducing PoU, it is important not only to intensify the world grain production, supply, trade and stock, reduce their losses (starting from cultivation and ending with storage, processing, distribution and consumption), but also attend to their equal and faithful export and import, with observing by all countries the principles of the World Trade Organization and the United Nations Organization (D'Odorico et al, 2019; Duro et al., 2020 and others).

5. Conclusion

In accordance with its purpose, the study revealed the impact of demand and supply at the world grain market on the global level of malnutrition. The research has also revealed a stable interdependence of the indicators that characterize the world market of grain crops, in particular wheat, fodder grain and rice. This dependence is ambiguous. Thus, the analysis of the indices of the world grain market, the world wheat market, the world grain forage market and the world rice market has proven the tight relation between the world production, trade, supply, losses and the PoU level. According to the indicator *stock*, the relation is very low and the correlation-regression equations are statistically hardly reliable.

Among the indices under research, the most stable and statistically reliable one characterizing the world grain market is the indicator *trade*. Thus, all other things being equal, the volumes of world cereal trade have a 72,42% impact on the level of PoU, while the other 27,58% influence other factors. The built correlation-regression equation proves that the dependence under study is strong, statistically reliable and directly proportional. That is, with an increase in trade volumes by 1 million tons, the PoU level will increase by 0.018%. Accordingly, with an increase in world grain production by 1 million tons, the PU level will increase by 0.008%. Although while prognosing at the growth of the world grain trade by 5% in the 2023/24 marketing year, the level of prevalence of undernourishment will decrease by 0,18 percentage points and the prognosed value may make up 9,7 % in 2023, but at the more intensive growth the situation will be the opposite.

Thus, the objective factors that affect the level of PoU as indicators of the world market of grain crops (production, supply, losses, trade, stocks), although have a close, reliable connection, are characterized by direct influence. That is, with a significant increase of the world grain market indicators, the level of PoU will not decrease, but on the contrary, it will increase, which was the tendency in recent years. Therefore, alongside with fighting climatic changes, applying new technologies of food production and reducing their production costs, combating socio-economic and political problems, it is necessary to attend to subjective factors. It concerns faithful, equal and uniform export and import of food products, in particular grains (wheat, grain forage, rice etc.). Besides, The World Trade Organization and the United Nations Organization have to withdraw unsubstantiated subjective unilateral sanctions on part of the developed countries on the export and import of grains and other food products to the countries with the high level of PoU (The Central African Republic, Madagascar, Haiti, Afghanistan, Chad, Congo, Lesotho, Liberia, Mozambique and others).

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