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Impact of coronavirus disease (COVID-19) on food security: bibliometric analysis and empirical evidence

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Impact of coronavirus disease on sustainable growth and food security is dramatically negative. Despite significant number of publications focused on food security and coronavirus disease issues, a deeper analysis of food security damages activated by COVID-19 is necessary. This determines the main task of this research. Theoretical block of the study involves bibliometric analysis of relevant Scopus publications using VOSviewer. Empirical block of the study involves: 1) formation of Food Security Index for 15 European countries based on a combination of Principal Component Analysis, ranking, Fishburn formula and additive convolution; 2) panel data regression modelling aimed at clarifying impact of macroeconomic indicators and healthcare expenditures on food security during 2000–2021 (model 1), 2000–2019 (model 2) and 2020–2021 (model 3). Model 1 demonstrates that 1% increase in current health care expenditures leads to 0.003units increase in Food Security Index; impact of the dummy variable characterizing COVID-19 pandemic is also positive. Model 2 demonstrates similar results. Model 3 confirms only positive and statistically significant impact of trade and agricultural land on Food Security Index. The results can be useful to government officials for adjusting political measures in food governance, political decision-making and good governance, recovery of sustainable growth in post-pandemic period.

KEYWORDS

coronavirus disease, COVID-19, food security, food governance, political decision-making and good governance, sustainable growth

1. Introduction

The COVID-19 pandemic, which began at the end of 2019 and continues nowadays, is a severe challenge for the entire global community. The coronavirus disease pandemic led not only to the large-scale human losses but also to negative socioeconomic consequences caused by the lockdown. According to the joint report of the FAO, IFAD, UNICEF, WFP and WHO "The State of Food Security and Nutrition in the World 2022. Repurposing food and agriculture policies that make healthy diets more affordable" (FAO, 2022), as of 2022, there are already more than 3 billion people in the world who are "unable to afford a healthy diet," which is partly due to the rise in food prices because of the pandemic. However, it is likely that the food security situation may vary significantly depending on the level of its pre-pandemic resilience in the country.

Considering the above, deepening of theoretical and empirical studies aimed at identifying the impact of the COVID-19 pandemic on food security is gaining relevance.

In the context of identifying more specific scientific theoretical and empirical results, the literature review block is organized into such subsections: 1) analysis of the main studies on food security; 2) analysis of the research on the impact of the COVID-19 pandemic on various spheres of socioeconomic life, in particular, and specific studies focused on identifying the impact of the COVID-19 pandemic on food security.

Ensuring food security occurs under the simultaneous influence of a significant number of factors. It has been proven that global trends towards urbanization in general have a positive impact on economic growth and food security (Vasylieva and James, 2021). On the other hand, the introduction of ecologically responsible approaches in agriculture serves as an incentive for the growth of food security (Lyulyov et al., 2019; Plastun et al., 2021; Makarenko et al., 2022; Morkūnas et al., 2022). Thus, key trends in the development of agriculture in European countries prove that in recent years business patterns of transition to sustainable agricultural development have become increasingly popular (Sapolaitė et al., 2019; Niu et al., 2021). Environmental policy (Hrytsenko et al., 2017; Polyakov et al., 2021) and environmental investment (Chygryn and Krasniak, 2015; Keliuotytė-Staniulėnienė and Daunaravičiūtė, 2021) are equally important determinants of both the development of sustainable agribusiness and the ensuring various perspectives of national security. In addition, in this direction, scientists (Vasylieva et al., 2020; Lyulyov et al., 2021; Samusevych et al., 2021) have also studied the impact of environmental taxes on the provision of various perspectives of national security (including food security).

At the same time, food security depends not only on the prerequisites for sufficient food supply created in the country but also on the effectiveness of economic regulation tools that determine household demand for quality food products. In particular, scientists Vasylieva (2021) and Dudek (2022) proved that such factors as price, total income, household structure, social capital, as well as individual factors characterizing the country's population play a significant role in ensuring food security.

Moreover, in recent years, the level of economic security of the country and its components (in particular, food security) increasingly depends on the processes of digitalization and technological development (Botos et al., 2020; Chee and Karhulahti, 2020; Lopez and Alcaide, 2020; Nagy et al., 2020; Sawangchai et al., 2020; Winiarski et al., 2021; Yarovenko et al., 2021). In particular, the ability to order food delivery and remote catering made it possible to mitigate severe threats to food security during the acute phase of the COVID-19 pandemic (Castillo-Vergara et al., 2021; Jasińska-Biliczak, 2022). In particular, in the study Hasan et al. (2022), it is determined that control of food supply chains is crucially important during the pandemic period. Coluccia et al. (2021) also researched the impact of COVID-19 on the supply chain. Authors underlined that the pandemic forced people to irrationally buying of conservable goods to create stocks for the lockdown period. Moreover, the authors found that during the lockdown, people preferred buying products in small shops instead of big supermarkets to avoid long queues. They also revealed that during the first months of the pandemic people preferred buying foodstuffs among other categories of goods (in comparison with the same period in 2019). The pandemic lockdown also significantly damaged trade relationships and channels of food supply. It increased demand for domestic products (locally produced). Coluccia and Agnusdei (2022) also researched the agrifood supply chain using bibliometric and trend analysis. The authors pointed out the significant importance of the supply chain in ensuring sustainable development. They also revealed that researchers pay more attention to environmental determinants of agrifood production sustainability, while social and economic determinants are considered less contributing to food industry sustainability. Therefore, it can be concluded that the food supply chain has been significantly transformed during the pandemic. The authors also argued that digital technologies are crucial in promoting sustainability and resilience of the food supply chain. At the same time, one of the COVID-19 consequences is a shift from traditional trade to electronic trade, which consequently is reflected in the development of the food industry (Waliszewski and Warchlewska, 2021; Jasińska-Biliczak, 2022).

The COVID-19 pandemic affected not only the food and shopping habits of the population, their quality of life and health but also triggered a radical transformation of the basic principles of stimulating the country's economic and social development. Significant reductions in working hours and employment (Tovmasyan and Minasyan, 2020; Černá and Hejduková, 2022; Kramarova et al., 2022; Privara, 2022) together with the maintaining requests for goods and services led to the necessity of development a special government support programmes for business and economic recovery (Androniceanu, 2020; Boronos et al., 2020; Tommaso, 2020; Krüger and Meyer, 2021; Vasilyeva et al., 2021). The scale of the negative impact of the COVID-19 pandemicvaries significantly depending on the industry (Carrasco Sierra et al., 2020; Zain et al., 2020; Hinrichs and Bundtzen, 2021; Machová et al., 2021). At the same time, despite the negative impact of the pandemic on the performance indicators of companies, it still has some positive consequences, such as an increase in business innovation (Fila et al., 2020; Antonyuk et al., 2021; Kliuchnikava, 2022; Navickas et al., 2022), which is designed to ensure the increase in the efficiency of internal business processes and the competitiveness of business as a whole. Quite interesting are the results of an empirical study, which showed that during the pandemic, consumers demonstrate more energy-efficient behaviour (Pop et al., 2022). This leads to the conclusion that global shocks trigger more responsible decisions regarding resource consumption. The pandemic also triggered a more intensive development of e-government (Kuzior et al., 2021; Makarenko et al., 2021).

Studies of the pandemic's impact on economic development have already become widespread. They are characterized by a significant variety of methods. The volume of scientific publications devoted to the study of the economic consequences of COVID-19 must be already sufficient for a successful bibliometric analysis (Cristian et al., 2022). In particular, it is found that the study of the consequences of the pandemic and the search for ways of post-pandemic recovery attract the attention of scientists with a broad geography, who form whole clusters of researchers from different countries (Liu et al., 2021).

A particular block of scientific research is devoted to analysing the prerequisites for variation in the vulnerability to the destructive impact of the COVID-19 pandemic, as well as the search for the fastest and most effective post-pandemic recovery mechanisms. Thus, scientists (Prokopenko et al., 2020; Smiianov et al., 2020; Lyeonov

S. et al., 2021; Lyeonov S. V. et al., 2021) emphasize that the effectiveness of overcoming the negative consequences of the pandemic depends significantly on the quality of management in the health care system. Researchers noted that the first consequences of the pandemic were much more robust in countries with a higher degree of economic freedom and lower intensity of regulation (Dempere, 2021). Therefore the review of approaches to the optimal level of regulatory burden is one of the potential directions of public policy and good governance transformation at the stage of post-pandemic recovery. The shadow economy is another negative factor affecting sustainable economic growth recovery after the COVID-19 pandemic (Shpak et al., 2020). On the other hand, in some countries, the pandemic has almost no effect on the structure of public expenditures (Abbasov et al., 2021). In general terms, researchers believe that in order to overcome the consequences of the pandemic effectively, it is necessary to coordinate the efforts of different countries in terms of the development and implementation of the post-pandemic recovery policy (Androniceanu, 2020), which key vector is the development of the system of early warning and response to threats to national security as a whole and its elements specifically (including food security) (Alkubaisy, 2020; Dutta et al., 2020; Drelich-Skulska and Domiter, 2020; Mikhnevych et al., 2020).

Despite the existence of a significant number of publications focused on the study of prerequisites for ensuring the country food security, as well as research in the field of identifying the impact of the COVID-19 pandemic on various spheres of socioeconomic life, an interesting scientific direction that is not so widely researched is a more profound analysis current processes in the field of food security, activated by the COVID-19 pandemic. All this confirms the relevance of this study.

2. Materials and methods

Therefore, the main task of this study is to identify the impact of the COVID-19 pandemic on food security. The practical implementation of the task involves the sequential implementation of several stages, namely:

- realization of bibliometric analysis with the VOSviewer_1.6.17 toolkit (VOSviewer, 2022) to form a theoretical background for the empirical analysis of the impact of the COVID-19 pandemic on the country food security;
- formation of an integral indicator of food security, which involves such stages as the formation of an array of partial indicators and bringing them to a comparable form through the normalization procedure according to the minimax method; determining the importance of partial indicators in the integral indicator based on the combination of Principal Component Analysis and the ranking approach; integration of partial indicators into the Food Security Index (FSI) using the Fishburn formula and additive convolution;
- determination of the acceptable form of the regression model (model with fixed or random effects) based on the Hausman test, implemented using the Stata 12/SE software product;
- determination of the impact of the COVID-19 pandemic on food security based on panel data regression modelling (GLS regression) by introducing a dummy variable characterizing the COVID-19 pandemic and comparing the simulation results in the pre-pandemic period and the pandemic period.

Calculations will be made for 15 European countries: Albania, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Moldova, Poland, Romania, Serbia, Slovakia, Slovenia, and Ukraine. The time horizon of the research is 2000–2021.

2.1. Bibliometric analysis

In order to form a theoretical basis for the empirical analysis of the impact of the COVID-19 pandemic on the country's food security, it is advisable to perform a bibliometric analysis of the relevant Scopus publications using the VOSviewer_1.6.17 toolkit (VOSviewer, 2022). Therefore, the main task of this research stage is to identify contextual patterns in Scopus publications with the keywords "food security" and "COVID-19." The bibliometric analysis allows identifying clusters of research based on the co-occurrence of key concepts used in papers' titles, abstracts, and keywords. It helps to clarify the most popular research topics, the interrelations between them and underline the research gap. A network visualization map created with the VOSviewer_1.6.17 toolkit (VOSviewer, 2022) helps to identify cohesion between different concepts mentioned in publications, which are collected considering search requests. These key concepts are united in specific contextual clusters that allow identifying specific vectors of scientific results. The number of items in the cluster help to clarify the popularity of the research direction. The size of the contextual clusters also might bring to the assumption of the research gaps. The bubble's size demonstrates the concept's popularity in the collection of selected scientific papers and the intensity of its co-occurrence with other keywords.

2.2. Food security index

The Food and Agricultural Organization of the United Nations defines indicators that characterize food security. However, there is a need to integrate them into a single indicator (with an acceptable range of observations) to obtain a more comprehensive picture of food security. It is also worth emphasizing that The Economist Group developed the Global Food Security Index (2022), which considers 58 indicators that reflect different projections of food security. However, Global Food Security Index (2022) is calculated only from 2012, which does not allow to provide empirical calculations in a longer time horizon. In addition, it should be noted that some of the food security indicators defined by the UN Food and Agriculture Organization (FAOSTAT, 2022) have missing observations. Therefore, the list of indicators on which this study will be based includes the following 19 food security indicators:

- Average Dietary Energy Supply Adequacy (I_1.1);
- Average value of food production, constant 2004–2006 I$ per caput (I_1.2);
- Share of dietary energy supply derived from cereals, roots and tubers, % (I_1.3);
- Average protein supply, gr/caput/day (I_1.4);
- Average supply of proteins of animal origin, gr/caput/day (I_1.5);

- Rail lines density, total route in km per 100 square km of land area (I_2.1);
- GDP *per capita*, constant 2011 international $ (I_2.2);
- Prevalence of undernourishment, % (I_2.3);
- Depth of the food deficit, kcal/caput/day, (I_2.4);
- Cereal import dependency ratio, % (I_3.1);
- Percent of arable land equipped for irrigation, % (I_3.2);
- Value of food imports over total merchandise exports, % (I_3.3);
- Political stability and absence of violence, Index (I_3.4);
- *Per capita* food production variability, constant 2004–2006 thousand international $ *per capita* (I_3.5);
- *Per capita* food supply variability, kcal/caput/day (I_3.6);
- Percentage of population with access to improved drinking water sources, % (I_4.1);
- Percentage of population with access to sanitation facilities, % (I_4.2);
- Prevalence of obesity in the adult population (18 years and older), % (I_4.3);
- Prevalence of anemia among women of reproductive age (15–49 years), % (I_4.4).

Given that all indicators have different measurement units, it is objectively necessary to bring them to a comparable form through the normalization procedure using the minimax method. For this purpose, all partial indicators are divided into stimulants (the growth of the indicator has a positive effect on the overall level of food security) and inhibitors (the growth of the indicator harms the level of food security). Most indicators are stimulants. Such indicators as I_2.3, I_2.4, I_3.3, I_4.6 and I_4.7 are defined as inhibitors. Determination of the normalized value of the stimulant indicator occurs by dividing the actual value of the indicator by its maximum value for the sample as a whole. The determination of the normalized value of the inhibitor indicator occurs by dividing the minimum value of the sample as a whole by the actual value of the indicator. After the normalization procedure, all values of the partial indicators of the food security characteristic will belong to the range [0; 1].

At the next stage, all normalized values of the indicators will proceed using Principal Component Analysis in the Stata 12/SE software. In particular, for further calculations, the eigenvalues of the indicators within the principal components, which cumulatively explain more than 70% of the total variation of the variables, will be used. Averaged value of all absolute eigenvalues for the individual indicator within all selected principal components will be used as a basis for further ranking of the food security indicators. In particular, the highest value of the rank (19) will be assigned to that partial indicator for which the calculated average eigenvalue will be the largest. This will indicate its higher importance in forming the Food Security Index. The ranks vary from 1 to 19, which is determined by the total number of partial indicators.

The next stage is the determination of weights for each of the partial indicators according to the Fishburn formula. In particular, the weighting coefficients are determined by dividing the rank of the corresponding partial indicator by the total sum of all ranks (190).

The weights will be used to form the Food Security Index using additive convolution. As a result, the value of the Food Security Index, as well as partial indicatorsbelongs to the range [0; 1]. At the same time, a higher value of FSI indicates a better state of food security in the country.

2.3. Hausman test and regression analysis

To determine the impact of COVID-19 on food security, a panel data regression modelling tool, namely GLS regression, will be used. The functional form of the model – a model with fixed or random effects – will be determined using the Hausman test. All computations will be implemented using the built-in tools of the Stata 12/SE software.

It should be noted that the dependent variable in all models will be the food security index calculated at the previous stage. A set of independent variables are indicators of the characteristics of the macroeconomic situation in the country, namely:

- GDP growth (annual %) (GDPg);
- Gross capital formation (% of GDP) (GCF);
- General government final consumption expenditure (% of GDP) (GGFCE);
- Inflation, consumer prices (annual %) (Infl);
- Trade (% of GDP) (Trade);
- CO2 emissions (metric tons *per capita*);
- Unemployment, total (% of total labor force) (modeled ILO estimate);
- Agricultural land (% of land area).

The indicators characterizing the impact of the pandemic are the following: Current health expenditure (% of GDP) (CHE) and a dummy variable (Dummy), which takes the value of "0" in the pre-pandemic period and "1" - in the pandemic period (2020–2021). All independent variables (except the dummy one) are formed from the World Development Indicators collection of The World Bank DataBank (2022).

In addition, in order to compare the scale of influence of independent variables on the Food Security Index, two alternative regression models will be constructed without dummy variable. Model 1 will reflect the relationships between variables in the pre-pandemic period (2000–2019) and model 2 – in the pandemic period (2020–2021). All these results in a complex will allow finding out the scale of changes in the impact of macroeconomic indicators on the variation of food security level caused by the COVID-19 pandemic.

3. Results

This section presents the research results, which is to identify the impact of the COVID-19 pandemic on food security.

3.1. Bibliometric analysis

According to the results of the search request considering "food security" and "COVID-19" in the Scopus database (Scopus, 2022), it is found 1,838 documents that meet the search criteria. These scientific

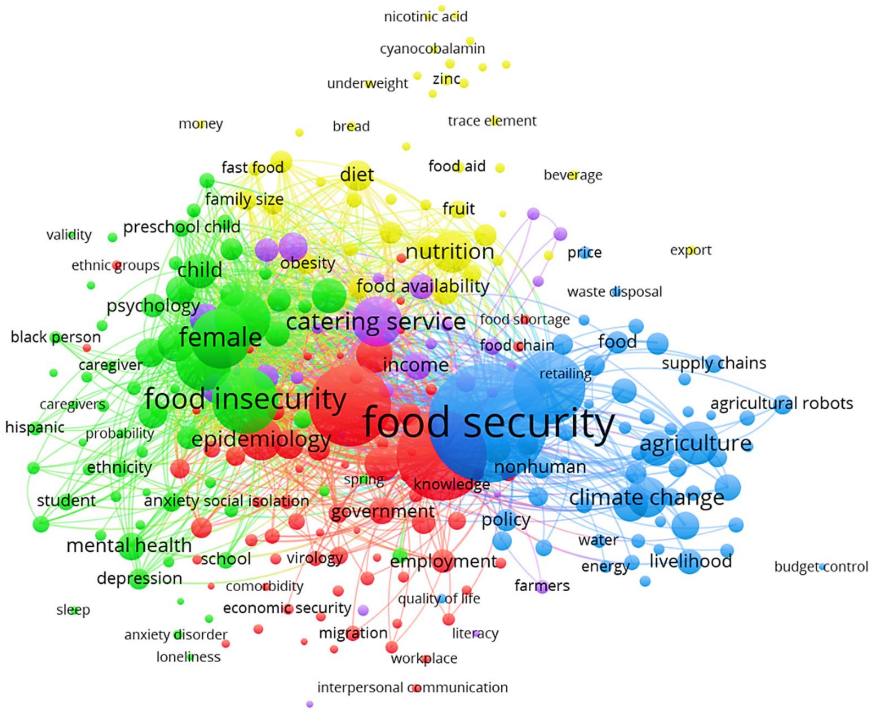

FIGURE 1
Network visualization key concepts co-occurrence in Scopus (2022) publications on "food security" and "COVID-19" realized with VOSviewer_1.6.17 toolkit (VOSviewer, 2022).

works were published in 2020 (221 documents), 2021 (837 documents) and 2022 (780 documents). Network visualization of the co-occurrence between key concepts in these publications is presented in Figure 1.

As can be seen from Figure 1, all Scopus publications with the keywords "food security" and "COVID-19" can be conditionally divided into five contextual clusters, namely:

- red cluster (73 keywords) – includes studies focused on epidemiological problems, issues of the development of the health care system, economic and financial consequences of the pandemic, the effectiveness of the state policy to combat the spread of coronavirus disease (lockdown, quarantine restrictions, vaccination, etc.), social interaction in conditions of a pandemic, etc.;
- green cluster (64 keywords) – includes studies on the influence of age, education, family, gender, mental and physical factors, and income levels of the households on food security;
- blue cluster (56 keywords) – covers research concerning the impact of agriculture development (animal husbandry, fish farming, crop yields), the sufficiency of arable land and water resources, the impact of environmental factors and the quality of waste management on food security;
- yellow cluster (45 keywords) – covers the works of scientists in the field of the relationship between dietetics (dietary balance both from the point of view of the consumption of proteins, fats, carbohydrates and total caloric content and from the point of view of the sufficiency of trace elements and minerals in food) and food security, promotion of healthy nutrition and active lifestyle;
- purple cluster (31 keywords) – covers publications on the impact of food availability and catering on food security projections.

Thus, based on the results of the bibliometric analysis, it is possible to underline the existence of specific contextual clusters of scientific research. It is fair to note that 4 out of 5 contextual clusters are focused on studying various prerequisites for ensuring food security. In contrast, only one cluster (red, the largest) includes publications related to the study of the impact of the pandemic on specific areas of socioeconomic life. This brings us to the conclusion that there is a research gap, and it is needed to provide a more in-depth analysis of the influence of the COVID-19 pandemic on the state of food security in different countries.

3.2. Food security index

Therefore, this stage of the study considers the formation of the Food Security Index. After bringing all 19 food security indicators into comparative form, Principal Component Analysis in the Stata 12/ SE software was applied. The results of this stage of the research are presented in Table 1.

For further research, it is necessary to select those principal components that cumulatively explain more than 70% of the total variation of the variables. According to Table 1, it can be noted that exactly five principal components meet the specified threshold, and therefore they will be used for further calculations.

At the next stage, it is determined the average values of the absolute (modulo) eigenvalues for each individual indicator, identified

their corresponding rank and calculated the weighting coefficients using the Fishburn formula. This stage helps reveal the relevance of each of the 19 food security indicators. The results of this stage are presented in Table 2.

According to Table 2, it can be noted that the most relevant factors for ensuring food security in 2000–2021 for the selected 15 European countries are "Rail lines density" (I_2.1), "Prevalence of anemia among women of reproductive age (15–49 years)" (I_4.4) and "Depth of the food deficit" (I_2.4). The high relevance of these parameters is confirmed by their highest ranks determined based on the eigenvalues averaged over the five principal components. These indicators also have the highest weighting coefficients in the Food Security Index.

At the same time, it is found that among the individual indicators of food security, the least significant are as follows: "Political stability and absence of violence" (I_3.4), "Average protein supply" (I_1.4) and "GDP *per capita*" (I_2.2), because these indicators have the lowest ranks and weighting coefficients, respectively. Considering the obtained results, it can be noted that the economic and political situation in the country does not have a decisive influence on the level of food security in the developed and developing countries included in the sample. Instead, the development of transport infrastructure and the diet quality (especially among the female population of reproductive age) largely determine the state of food security in the selected European countries.

At the next stage, the Food Security Index is formed by multiplying the actual normalized value of the individual indicator of food security by the corresponding weighting coefficient (the last column of Table 2). Descriptive statistics for the Food Security Index and independent variables are presented in Table 3.

According to the data from Table 3, it can be noted that the Food Security Index in the selected 15 European countries ranges from 0.42 to 0.68. The highest level of food security is in the Czech Republic and Hungary, and the lowest – in Serbia, Moldova and Slovenia. On average, for 2000–2021, the Food Security Index in the selected 15 European countries was 0.515. That is countries use only half of their existing potential to ensure food security.

It is also worth noting that the panel is strongly balanced because there are no omitted observations. However, some variables still had missing values, which were predicted by extrapolation considering the existing trend.

3.3. Hausman test and regression analysis

The next stage of this study is the implementation of regression analysis to test the scientific hypothesis of the study. In particular, the hypothesis of a change in the scale of influence of key macroeconomic indicators in 15 studied European countries on the variation in the level of food security caused by the COVID-19 pandemic is empirically tested. In addition, it is also established how such determinants of the development of the pandemic as Current health expenditure (% of GDP) (CHE) and a dummy variable (Dummy) influenced the change in the country's Food Security Index.

Before proceeding to the modelling and characterizing the empirical results, it is necessary to determine the appropriate form of the regression model (fixed or random effects model) based on the Hausman test. In particular, according to the test results, it is established that "Prob>chi2 = 0.9497." The results indicate the need to reject the null hypothesis and accept the alternative one. Thus, the form of the regression model with random effects is more acceptable.

The results of the regression analysis regarding the determination of the impact of macroeconomic determinants on the level of food security in 15 European countries for the period 2000–2021 are presented in Table 4.

According to the modelling results, the following conclusions can be drawn:

- for the entire observation period for a sample of 15 European countries, only the impact of trade on the country's food security is statistically insignificant; the rest of the independent variables have statistical significance at one of the acceptable confidence intervals (99, 95% or 90%);
- GDP growth, Gross capital formation, General government final consumption expenditure, Inflation and Unemployment harm the Food Security Index; in particular, an increase in independent variables by 1 unit leads to a decrease in the dependent variable by 0.0006, 0.0011, 0.0015, 0.0005 and 0.0014 units, respectively;
- an increase of 1 metric ton *per capita* of CO2 emissions leads to an increase in the Food Security Index by 0.0073 units at a 99% confidence interval;
- an increase of 1% Agricultural land to land area ratio leads to an increase in the Food Security Index by 0.0014 units at the 99% confidence interval;
- at the same time, the quality of the healthcare system also has a positive effect on the growth of the Food Security Index (at a 95% confidence interval), namely: a 1% increase in the share of current healthcare expenditures in GDP leads to an increase in the dependent variable by 0.003 units, which is one of the largest in terms of strength and scale of influence of relationships between dependent and independent variables of the model;
- interesting is that for the selected 15 European countries characterized by a satisfactory state of food security, the effect of the dummy variable characterizing the COVID-19 pandemic on the dependent variable is also positive and statistically significant at the 99% confidence interval.

The next stage is a comparison of regression modelling results of macroeconomic indicators' impact on the Food Security Index in selected 15 European countries in the pre-pandemic period – 2000-2019 (Table 5) and the pandemic period – 2020-2021 (Table 6).

According to the data presented in Tables 5, 6, it can be noted that the results of regression modelling regarding the identification of the influence of factors on food security in the pre-pandemic period (2000–2019) in terms of strength, direction and statistical significance of the indicators are practically duplicate the results for the entire observation period, which are presented in Table 4.

However, according to the modelling results during the pandemic period (2020–2021), the statistically significant influence of the selected independent variables on the Food Security Index is almost not confirmed. In particular, it is found that only two factors have a positive impact on the Food Security Index.

TABLE 1 Principal component analysis results.

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	6.799	4.272	0.358	0.358
Comp2	2.527	0.306	0.133	0.491
Comp3	2.222	0.807	0.117	0.608
Comp4	1.415	0.318	0.074	0.682
Comp5	1.097	0.084	0.058	0.740
Comp6	1.013	0.033	0.053	0.793
Comp7	0.980	0.279	0.052	0.845
Comp8	0.701	0.172	0.037	0.882
Comp9	0.529	0.060	0.028	0.910
Comp10	0.469	0.203	0.025	0.934
Comp11	0.266	0.015	0.014	0.948
Comp12	0.251	0.069	0.013	0.962
Comp13	0.182	0.024	0.010	0.971
Comp14	0.158	0.035	0.008	0.979
Comp15	0.123	0.024	0.006	0.986
Comp16	0.099	0.022	0.005	0.991
Comp17	0.077	0.020	0.004	0.995
Comp18	0.057	0.019	0.003	0.998
Comp19	0.038		0.002	1.000

TABLE 2 Weighting coefficients of food security indicators.

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Average	Rank	Weights
I_1.1	0.260	0.414	0.079	0.024	0.123	0.180	7	0.036842
I_1.2	0.147	0.280	0.306	0.053	0.282	0.213	14	0.073684
I_1.3	0.278	0.160	0.163	0.13	0.206	0.187	10	0.052632
I_1.4	0.294	0.065	0.071	0.125	0.105	0.132	2	0.010526
I_1.5	0.234	0.414	0.063	0.083	0.198	0.198	11	0.057895
I_2.1	0.214	0.352	0.041	0.254	0.382	0.249	19	0.100000
I_2.2	0.32	0.033	0.037	0.282	0.069	0.148	3	0.015789
I_2.3	0.319	0.170	0.122	0.074	0.061	0.149	4	0.021053
I_2.4	0.221	0.180	0.182	0.033	0.569	0.237	17	0.089474
I_3.1	0.056	0.234	0.513	0.178	0.044	0.205	12	0.063158
I_3.2	0.174	0.313	0.147	0.194	0.255	0.217	15	0.078947
I_3.3	0.204	0.287	0.111	0.450	0.100	0.231	16	0.084211
I_3.4	0.282	0.155	0.16	0.043	0.015	0.131	1	0.005263
I_3.5	0.021	0.057	0.502	0.211	0.244	0.207	13	0.068421
I_3.6	0.064	0.055	0.026	0.425	0.346	0.183	8	0.042105
I_4.1	0.245	0.139	0.209	0.182	0.059	0.167	5	0.026316
I_4.2	0.237	0.203	0.323	0.021	0.146	0.186	9	0.047368
I_4.3	0.328	0.028	0.15	0.241	0.122	0.174	6	0.031579
I_4.4	0.100	0.19	0.259	0.465	0.196	0.242	18	0.094737

Specifically, the growth of the total volume of exports and imports to GDP ratio in 1% leads to an increase in the Food Security Index by 0.0008 units at a 90% confidence interval, as well as a 1% increase in Agricultural land to total land area ratio leads to an increase in the Food Security Index by 0.002 units at the 90% confidence interval).

TABLE 3 Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
FSI	330	0.515	0.06	0.42	0.68
GDPg	330	3.281	4.229	−15.14	13.94
GCF	330	24.559	5.236	8.93	41.59
GGFCE	330	18.242	2.700	9.69	24.19
CHE	330	6.802	1.268	4.21	13.68
Infl	330	5.256	8.423	0.03	95.01
Trade	330	111.147	32,885	22.49	190.70
Unem	330	9.828	4.583	2.01	24.00
CO2	330	5.835	2.845	1.03	14.90
AgrL	330	45.818	15.809	16.47	77.37

TABLE 4 Regression results (random-effects GLS regression) on the influence of macroeconomic indicators on Food Security Index for 15 European countries in 2000–2021.

FSI	Coef.	St.Err.	*t*-value	value of *p*	95% confidence interval		Sig
GDPg	−0.000559	0.000243	−2.30	0.021	−0.001	0.000	**
GCF	−0.001086	0.000257	−4.23	0.000	−0.002	−0.001	***
GGFCE	−0.001488	0.000761	−1.96	0.050	−0.003	0.000	*
CHE	0.002959	0.001334	2.22	0.026	0.000	0.006	**
Infl	−0.000522	0.000127	−4.12	0.000	−0.001	0.000	***
Trade	0.000094	0.000062	1.52	0.129	0.000	0.000	
Unem	−0.001354	0.000322	−4.20	0.000	−0.002	−0.001	***
CO2	0.007258	0.001377	5.27	0.000	0.005	0.010	***
AgrL	0.001396	0.000328	4.25	0.000	0.001	0.002	***
Dummy	0.013944	0.003503	3.98	0.000	0.007	0.021	***
Constant	0.448461	0.026312	17.04	0.000	0.397	0.500	***

It should be noted that the influence of the last indicator on the dependent variable is even stronger compared to the modelling results for the period 2000–2021 and 2000–2019.

4. Discussion

In the previous studies of the authors (Vysochyna et al., 2020), it was already proposed to form an integral indicator of food security using the same 19 indicators. However, the previous approach had a number of shortcomings, which were fixed in this work, namely: 1) the use of only the first principal component for the formation of the Food Security Index, which cumulatively explained less than 50% of the total variation of the variables, while in this work it is used average values within five principal components that explain 74% of the total variation of variables; 2) the use of eigenvalues of the first principal component as weighting coefficients of individual indicators in the integral, which did not allow to accurately identify the strength and significance of the influence of indicators, as well as qualitatively interpret the change in the Food Security Index, and its maximum value; in the current work, a more complex algorithm for determining the weighting coefficients of individual indicators is used, based on a combination of Principal Component Analysis, ranking, and the Fishburn formula, which made it possible to more clearly establish the significance of the influence of individual indicators in the integral index, as well as to form it in such a way that it has a precise range of variation – [0; 1], which facilitates the qualitative characterization of the obtained results. At the same time, comparing the developed Food Security Index with the Global Food Security Index (2022) for 8 of the 15 countries of the sample for 2012–2021 allows identifying the correlation between these indices is 0.8684. It indicates the satisfactory predictive and prognostic quality of the approach developed in the current work to the integral assessment of the country's food security level.

Results of the Food Security Index construction for the 15 European countries revealed that the performance indicator mostly depends on the railway network density, cases of anemia among women of reproductive age and the state of food deficit. These three indicators mainly contribute to the food security change in analyzed countries. It was also clarified that political stability, protein supply and GDP *per capita* are not significant determinants of food security volatility. Therefore, it can be concluded that the state of food security is somewhat sensitive to logistic damages but quite resistant to political uncertainty and violation of economic well-being. Moreover, women are more fragile in terms of food security violations. It also

TABLE 5 Regression results (random-effects GLS regression) on the influence of macroeconomic indicators on Food Security Index for 15 European countries in pre-pandemic period (2000–2019).

FSI	Coef.	St.Err.	*t*-value	value of *p*	95% confidence interval		Sig
GDPg	−0.000745	0.000269	−2.77	0.006	−0.001	0.000	***
GCF	−0.001127	0.000268	−4.20	0.000	−0.002	−0.001	***
GGFCE	−0.001712	0.000794	−2.16	0.031	−0.003	0.000	**
CHE	0.002681	0.001444	1.86	0.063	0.000	0.006	*
Infl	−0.000547	0.000126	−4.33	0.000	−0.001	0.000	***
Trade	0.000062	0.000063	0.98	0.326	0.000	0.000	
Unem	−0.001437	0.000321	−4.48	0.000	−0.002	−0.001	***
CO2	0.007042	0.001397	5.04	0.000	0.004	0.010	***
AgrL	0.001519	0.000339	4.47	0.000	0.001	0.002	***
Constant	0.456195	0.026869	16.98	0.000	0.404	0.509	***

TABLE 6 Regression results (random-effects GLS regression) on the influence of macroeconomic indicators on Food Security Index for 15 European countries in pandemic period (2020–2021).

FSI	Coef.	St. Err.	*t*-value	value of *p*	95% confidence interval		Sig
GDPg	−0.000923	0.000633	−1.46	0.145	−0.002	0.000	
GCF	0.001188	0.001194	1.00	0.319	−0.001	0.004	
GGFCE	−0.000994	0.005399	−0.18	0.854	−0.012	0.010	
CHE	−0.006354	0.013488	−0.47	0.638	−0.033	0.020	
Infl	0.000689	0.001342	0.51	0.607	−0.002	0.003	
Trade	0.000803	0.000437	1.84	0.066	0.000	0.002	*
Unem	−0.000542	0.003192	−0.17	0.865	−0.007	0.006	
CO2	0.002109	0.007749	0.27	0.786	−0.013	0.017	
AgrL	0.002113	0.001341	1.58	0.105	−0.001	0.005	*
Constant	0.368000	0.171938	2.14	0.032	0.031	0.705	**

should be mentioned that Food Security Index varies from 0.42 to 0.68 during 2000–2021, while its average value is 0.515.

Consequently, it can be concluded that analyzed European countries have a potential for food security improvement. These improvements lie in the field of food product logistics and dietary optimization. Research results demonstrate that the Czech Republic and Hungary are more successful in ensuring food security, while Serbia, Moldova and Slovenia have some obstacles. The generalization of the theoretical results of this study, which consisted in the identification of the contextual clusters of scientific research on food security and COVID-19 based on bibliometric analysis, showed that 4 out of 5 clusters are focused on the study of various prerequisites for ensuring food security. In contrast, only one cluster (the largest) includes publications related to the study of the impact of the pandemic on specific areas of social and economic life.

Instead, the empirical results of this study prove that for the 15 selected European countries, the level of food security in 2020–2021 does not depend on the intensity of trade, is negatively affected by GDP growth, gross capital formation, general government final consumption expenditure, inflation and unemployment, while positively depends on the increase in CO2 emissions, Current health expenditure to GDP ratio and Agricultural land to total land area ratio. Consequently, food security in these countries significantly depends on the development of agriculture (this may be one of the reasons for the positive impact of CO2 emissions on food security because animal husbandry contributes significantly to this negative environmental impact) and the quality of financing the current needs of the healthcare system.

It is also worth noting that the dummy variable characterizing the pandemic also positively affects the state of food security in these countries. Although this conclusion seems contradictory, it can be explained by the following circumstances: (1) the selected 15 European countries in the pre-pandemic period did not have severe problems with food security, and therefore the COVID-19 pandemic and all accompanying restrictions did not harm the state of food security in these countries during the pandemic and (2) food security of the country is a complex parameter that takes into account not only the availability of food products but also their quality and balanced diet; all this leads us to the conclusion that quarantine restrictions and lockdown forced population tocare about own health (excess weight has been identified as one of the risk factors of severe health damage of coronavirus disease), consume healthy products and eat more rationally during this period, which positively reflected on the level of food security.

However, the impact of the pandemic on the state of food security in countries for which this problem was acute even in the pre-pandemic period can probably be catastrophically negative, which is confirmed by a number of studies (FAO, 2022; Feeding America, 2022; McDermott and Swinnen, 2022; UN Sustainable Development Group, 2022). In addition, in developed countries,

most of the processes related to the production of food are automated, which makes it possible to avoid large-scale consequences for food security in comparison with countries where the level of sufficiency and availability of food largely depends on humans (Ivanov et al., 2021; Laborde et al., 2022). Researchers Laborde et al. (2022) also confirm the hypothesis of significant differences in the structure of the diet among households in countries with high-, middle- and low-income levels. In particular, the analysis of more than 300,000 households found that poor households spend almost 50% of their income on vegetables, fruits or animal products. In contrast, the purchasing power of these households has decreased dramatically during the pandemic. All this harms the balanced diet of these households during the acute stage of the COVID-19 pandemic and therefore provokes food insecurity. At the same time, the same researchers Laborde et al. (2022) did not find such critical negative trends regarding food security and diet balance in countries with a high-income level. It also should be noted that the research results pointed out that during the pandemic, food security is boosted by the growth of trade volumes. At the same time, this determinant did not demonstrate a statistically significant influence on the performance indicator in the pre-pandemic period. Bajan et al. (2021) also found out familiar trends. Moreover, it was established that expanding agricultural land areas in the pandemic stimulated food security. The importance of agricultural sector development due to mitigating food insecurity damages has also been confirmed in numerous research (Stefan et al., 2020; Chen et al., 2021; Kotykova and Babych, 2021; Peng et al., 2021).

5. Conclusion

In the paper, it is constructed the Food Security Index for 15 European countries based on 19 indicators that characterize proxies of food availability, access to food, food utilization and food stability. The individual indicators' contribution scale was identified based on the Principal Component Analysis and ranking approach. Construction of the FSI allows considering national peculiarities. It provides a background for further empirical research [the existing Global Food Security Index (2022)] covers a relatively short period of observations that might negatively affect the significance of modelling results). Analysis of the Food Security Index dynamics allows for underlining the country sample's most significant determinants of food security improvement. It helps to point out more and less prosperous countries in food security ensuring. Empirical results on clarifying the impact of macroeconomic indicators and healthcare expenditures on food security allow concluded that during 2000–2021 the increase of CO2 emissions, current health expenditure and agricultural land positively contributed to the state of food security in the researched countries, while in the pandemic period only increase of trade volumes and agricultural land areas allow avoiding food security damages. These results make it possible to argue that in the pandemic period in the selected 15 European countries, food security depends on the ability to trade food with other countries and on the potential to meet the domestic food market's needs through internally produced agriculture products. Obtained empirical results demonstrate new, regionally specified and valuable findings concerning food security challenges during COVID-19.

The theoretical and empirical results obtained within the framework of this study can be useful both for scientists in the context of further and more profound scientific research and for representatives of the public sector administration. Government officials can use the results of the study to adjust the strategy to overcome the pandemic consequences and eliminate damages of the negative impact of similar threats on the country's food security in the future.

Among the limitations of the research can be mentioned as follows: (1) limited size of the country sample, expansion of the research to other geographical regions allows for obtaining more valuable, regionally specified empirical results and (2) small set of observations for the pandemic period (only 2 years), more comprehensive data might improve quality of the models.

Considering current research limitations, promising vector of further scientific research can be noted as follow: comparison of the impact of macroeconomic indicators and healthcare expenditures on food security in the pre-pandemic and pandemic periods in different country samples (country clusters might differentiate by continent, levels of food security in the pre-pandemic period, level of economic development, etc.). It might help to reveal differences in the COVID-19 pandemic impact on food security depending on the variation of socioeconomic or geographical preconditions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

AV, TV, YB, and DG: conceptualization. AV and LS: methodology. TV: software. AV, TV, and DG: validation and formal analysis. AV: investigation and writing—original draft preparation. DG and LS: resources. AV and TV: data curation. TV, YB, and LS: writing—review and editing. DG: visualization. YB: supervision. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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