Ensuring Global Food Security: Transforming Approaches in the Context of Agriculture 5.0

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Abstract. The article highlights the relationship between ensuring world food security and the pace of technological transformation of agriculture, taking into account the impact of global challenges, based on the study of theoretical approaches of leading scientists. The authors use analysis and synthesis, expert, statistical and comparative methods. The history of technological changes in agriculture are considered through its evolution from traditional food systems to Agriculture 5.0 – the post-industrial system with the use of robotics, big data and artificial intelligence systems. The authors prove that the level of agricultural development and the rate of its technological transformation are sharply differentiated by country. The cross-country analysis of indicators of food security, innovation potential, production and food net trade of the leading food-producing countries allowed us to draw two conclusions. First, developed countries that are at the top of the innovation rating and ensure national food security at a high level have negative food net trade. In the near future, these countries will not be able to have a significant impact on world food security. Secondly, countries with export-oriented agriculture are characterized by low innovation and have limited opportunities for labor productivity growth in agriculture.

1. Introduction

The main problem to be solved today by the world community is how to ensure global food security and eliminate hunger and malnutrition in the conditions of growing global population, continuing inequality of countries, limited resource potential of agriculture, increasing environmental risks, climate change and other challenges.

In the modern world, the relationship between solving the problem of ensuring global food security and the introduction of information technologies in agriculture is beyond doubt. In the history of mankind, the evolution of agriculture is a combination of smooth development and scientific and technological revolutions, which resulted in an increase in the efficiency of food production. Traditional food systems are gradually giving way to post-industrial food systems. One of the key drivers of the agricultural development in the 21st century is digital transformation.

The level of agricultural development and the rate of technological changes are sharply differentiated by country. It is impossible to compare, for example, the efficiency of agriculture in Burundi, which is at the stage of Agriculture 1.0-2.0, and the United States, where agriculture is characterized by rapid deployment of advanced biotechnologies and digital tools. Therefore, the search for an answer to the question of which countries will be able to transform food production in the future
according to the vector of information technology development and, thereby, contribute to ensuring global food security is of particular relevance, both in theory and in practice.

2. Materials and methods
The methodology of the article is determined by its purpose – to investigate the relationship between ensuring world food security and the pace of technological transformation of agriculture based on the study of theoretical and methodological approaches of leading scientists in this research field. The methodology takes into account the key features of the research object (agriculture) and is based on the use of a system of general scientific and special research methods, which allows solving a problem more effectively.

The research methods are analysis and synthesis (study of the content of the agricultural development stages, research of theoretical approaches to Agriculture 5.0), expert method (assessment of the effects of technological transformation of agriculture), statistical and comparative methods (study of the relationship between the innovative potential of the country and the level of agricultural development).

The information base of the study includes analytical and statistical data presented in the following sources: The Global Innovation Index 2020; Global Food Security Index 2020; World Stat Pocketbook 2020, World Food and Agriculture - Statistical Yearbook 2020, World Food and Agriculture – Statistical Pocketbook 2019.

3. Results and analysis
As noted above, world agriculture has gone a long way from the most primitive forms of agricultural production to the post-industrial model with its robotics, big data and the use of artificial intelligence systems.

Traditional agriculture was characterized by a high proportion of manual labor and low productivity, the participation of almost a third of the entire population in the food production process. This stage took place until the middle of the 20th century, it is called Agriculture 1.0.

The second stage of agricultural development began in the 50s of the 20th century – Agriculture 2.0 or “The Green Revolution”. This meant the development of agronomy, the implementation of plant and animal husbandry mechanization systems, the development of new fertilizers and pesticides. In general, the system of agricultural knowledge has undergone major changes, which has had a positive impact on increasing yields and productivity.

Agriculture 3.0 or "Precision farming" began after the introduction of telemechanical systems based on geolocation systems, including satellite ones, into the management of agricultural mechanisms. Agriculture 3.0 is characterized by intensive development of biotechnology and genetic engineering, differentiation of agricultural products based on data analysis (including obtained from remote sensors), optimization of agricultural production by reducing costs and increasing profitability.

Further development of information technologies in agricultural production led to the emergence of Agriculture 4.0, called "Digital agriculture" or "Smart farming". The main technologies of Agriculture 4.0 are artificial intelligence, big data, the Internet of Things, virtual and augmented reality, 3D printing, quantum computing, block chain and robotics. Modern production technologies of cheap microelectronic components and their miniaturization make it possible to design unmanned robotic systems for automated control of agricultural resources and mechanisms. Cloud storage systems and high-throughput communication technologies allow for real-time agricultural management decisions.

Artificial intelligence systems help to recognize reality and control drones, tractors, cars, and combines. Agriculture 4.0 can be considered a modern stage in the evolution of agriculture: its methods and tools are applied in the agricultural production of all developed countries.

Now agricultural technologies are evolving towards a new paradigm – Agriculture 5.0. However, many questions of Agriculture 5.0 are debatable, and the answers to them are only predictive. The development of bioeconomics in the concept of Society 5.0 suggests that the most promising areas of agricultural development are the optimal use of resources, mass personification and individualization
of the final product, the development of creative product differentiation and the introduction of autonomous automated decision-making systems based on robotic complexes. The absence of communication barriers in human-machine interaction, including with the use of bioinformatic technologies, will allow us to focus on increasing the heuristics of innovative decisions in agriculture.

Agriculture 4.0 and Agriculture 5.0 research are at the peak of popularity in agricultural science. We will consider the main theoretical and methodological approaches to the content, factors and conditions, methods of the modern technological stage of agricultural development, as well as its impact on food production and food security.

Agricultural expert Evan D. G. Fraser and journalist Andrew Rimas in the book “Empires of Food: Feast, Famine, and the Rise and Fall of Civilizations” talk about the cyclical nature of food crises in the history of civilization and suggest ways to prevent them [1]. By 2100, about 10 billion people will need carbon-neutral food systems that are resistant to extreme weather conditions and can bring positive socio-economic benefits to all participants in the food chain. Ensuring food security in these conditions requires new approaches. Food and farming systems must reconcile the need to produce enough healthy and affordable food with the important imperative of sustainable development of ecosystems. We must transit through the digital agricultural revolution into Agriculture 5.0 [2].

In scientific research digital agriculture is generally considered as the introduction of progressive methods of processing and interpreting digital data into agricultural production and management systems [3]. S. Shen, A. Basist, and A. Howard describe the category “digital agriculture” as an extension of the term “precision farming”. In their opinion, the digital basis of agriculture includes various types of data in the field of production and optimal decision-making, which makes possible more efficient management and marketing [4].

The integration of digital technologies into agricultural practices will allow to produce food on the principles of environmental friendliness and socio-economic efficiency [5]. To do this, it is advisable to use decision support systems in agriculture that operate with large data sets in order to improve farmers’ economic performance. An overview of thirteen representative decision support systems is presented in [6].

Given the high capital intensity of the digital transformation of agriculture, government support for the creation of innovative enterprises seeking to develop digital agriculture is of strategic importance. Technopolis and university incubation centres will be able to transform the accumulated scientific knowledge into enterprises and create an ecosystem oriented towards digital agriculture [7].

The issue of the effectiveness of digitalization of agriculture is debatable. Scientists agree that the effect will be positive, but the projected rate of efficiency growth varies widely. According to experts at Goldman Sachs, the introduction of new technologies could increase global agricultural productivity by 70% by 2050, which could have a huge impact on global food security [8]. Some authors pay particular attention to the serious social consequences of the digitization of agriculture, considering that it is necessary to ensure the social sustainability of agricultural production [9].

Scientists often analyze the digitalization of agriculture in the context of industrialization. Liu Y., Ma X., Shu L., Hancke G. and Abu-Mahfouz A. have investigated the development of industrial agriculture taking into account the impact of the industrial revolution [10]. The relationship between Agriculture 4.0 and Industry 4.0, in relation to the improvement of the mechanization of field work, is viewed in [11]. The researchers of Agriculture 5.0 and food security note that the use of artificial intelligence and robotics, as well as machine learning (ML) and deep learning (DL) can predict yields with a probability of 75%, detect diseases of crops, which affects the improvement of crop quality and increase the profitability of farms [12]. V. Saiz-Rubio and F. Rovira-Más say that the transition from Smart agriculture to Agriculture 5.0 in crop production should be accompanied by an even greater increase in productivity and sustainability, as well as the greening of agriculture [13]. It is therefore appropriate to consider Agriculture 5.0 in conjunction with Industry 4.0 and Society 5.0, developing environmentally sound technologies, creating sustainable smart cities, and ensuring industrial development as a standard of human well-being [14]. In this context, the concept of Edible Urbanism 5.0, proposed by A. Russo and G. T. Cirella, is very interesting [15].
In order to answer the main question of the study – which countries have the potential to contribute to ensuring global food security in the near future, and what is the role of the technological transformation of agriculture, we will carry out a cross-country analysis of indicators of food security, food production and innovation potential.

Today, countries are characterized by very high differentiation, both in the sphere of food production and in the sphere of food consumption. This determines the different level of their food security, that is, the supply and availability of food for a healthy and active life. To assess the level of food security in the world, it is calculated the global food security index – a composite indicator determined by The Economist methodology based on 34 indicators of food security in 113 countries [16].

The top 10 countries with a high level of food security include (in descending order of index): Finland, Ireland, Netherlands, Austria, Czech Republic, United Kingdom, Sweden, Israel, Japan, and Switzerland. The category of countries with the lowest food security includes (in ascending order of index) Yemen, Sudan, Zambia, Malawi, Sierra Leone, Ethiopia, Burundi, Madagascar, Haiti, Rwanda. Thus, the leaders are the countries with a high level of economic development, while the outsiders are the underdeveloped countries of Africa. It is noteworthy that some of the low-index countries are exclusively agricultural. So, in Burundi the share of agriculture in GDP in 2020 was 38.5 %, and the share of population employed in agriculture was 92 % – the highest in the world [17]. But labor productivity in Burundi is extremely low (agricultural value added per worker was $205 in 2017). This confirms the fact that, today, being part of an agrarian group of the countries does not guarantee a high level of food security. On the contrary, we agree with E. Reinert that a modern economically advanced industrial country can feed more people than an agrarian one [18].

Therefore, the objects of analysis of the growth potential of world food production are the leading countries of the world food market (table 1).

**Table 1.** Agricultural development indicators of leading food producers.

| Countries            | Value added of agriculture, forestry and fishing (USD million) [20] | Agricultural value added per worker, (2017) [21] | Share agriculture employment in total employment, % [20] | Food trade (USD million) [20] | Rank of the country in the Global Innovation Index 2020 [19] |
|----------------------|---------------------------------------------------------------------|-------------------------------------------------|--------------------------------------------------------|-----------------------------|----------------------------------------------------------|
| 1. China             | 1 073 100.2                                                         | 3 654                                           | 24.9                                                   | -74 729                     | 14                                                       |
| 2. India             | 398 681.1                                                          | 1 669                                           | 42.4                                                   | 12 504                      | 48                                                       |
| 3. United States of America | 183 901.1                                      | 79 108                                         | 1.3                                                    | -25 149                     | 3                                                        |
| 4. Indonesia         | 129 595.1                                                          | 3 632                                           | 28.6                                                   | 16 621                      | 85                                                       |
| 5. Nigeria           | 112 224.9                                                          | 5 597                                           | 35.1                                                   | -5 844                      | 117                                                      |
| 5. Brasil            | 83 110.4                                                           | 13 230                                          | 9.2                                                    | 62 141                      | 62                                                       |
| 6. Pakistan          | 67 491.2                                                           | 1 636                                           | 36.7                                                   | -1 447                      | 107                                                      |
| 7. Turkey            | 61 822.0                                                           | 15 308                                          | 18.4                                                   | 5 751                       | 51                                                       |
| 8. Russian Federation | 53 639.6                                                          | 15 880                                          | 5.8                                                    | -2 744                      | 47                                                       |
| 9. Iran (Islamic Republic of) | 46 377.0                                  | 10 209                                          | 17.9                                                   | -6 345                      | 67                                                       |
| 10. Japan            | 42 907.6                                                           | 23 954                                          | 3.4                                                    | -54 057                     | 16                                                       |

Agriculture value added in the world went up 68% between 2000 and 2018 to around USD 3.4 trillion. But the future prospects for global food production growth due to the technological transformation of the leading countries differ depending on the innovation potential of the economy and the value of food net trade.
The United States ranked first in the Global Innovation Index. This developed country is the world’s third most efficient food producer (agricultural value added per worker in 2017 - $79,108). The introduction of Agriculture 4.0 and Agriculture 5.0 technologies is intensive, which allows to further increase productivity in the agricultural sector of the economy. But the US is an industrial country. Agriculture does not contribute significantly to GDP (in 2019, the share of agriculture in gross value added was 0.9 % [17]), and net food trade is negative (-25,149 USD million). As a result, the innovative development of US agriculture will not have a significant impact on global food security. The same can be said about China and Japan, which are in the top-20 of the Global Innovation Index, but have a significant excess of food imports over exports. Thus, agricultural productivity growth of these countries will contribute to strengthening national food security, but not global.

India is the second largest food producer in the world. It is an agrarian country: the share of agriculture employment in total employment is 42.4 %. Food exports exceed imports by 12,504 USD million, indicating the export orientation of Indian agriculture. India exports basmati Rice, fresh vegetables and fruits, dairy products and other products. The Government of India launched comprehensive agriculture export policy to make India a leading player in the world food market. However, India had very low productivity and average innovation capacity, which limited its ability to increase food supply on the world market through innovation and productivity growth.

The Russian Federation and Turkey are in the middle of the Global Innovation Index. These are emerging economies that have so far been characterized by a predominantly extensive pattern of agricultural development, which determines modest productivity relative to developed countries. In terms of productivity, Iran is also approaching this group of countries. Given the medium food net trade in Turkey and negative one in Russia and Iran, the prospects for their impact on global food security are also very uncertain.

Nigeria and Pakistan are low-income countries with inefficient agriculture and negative food net trade. In these countries, agricultural productivity is low, with rapid population growth. Given the minimal potential for innovation, the probability of increasing food production by intensive means in these countries is low, and even national food self-sufficiency is at risk.

Brazil and Indonesia have export-oriented agriculture and have potential impacts on world food supply. Brazil ranks first in the world for food net trade. In the last decade the Brazilian agricultural sector has been transformed from a traditional system of production with low use of modern technologies to a world agricultural leader. Agricultural innovations have been most rapidly adopted by the most efficient farms [22]. Therefore, the introduction of Agriculture 5.0 will allow Brazil to increase labor productivity and food production and have a positive impact on global food security. In the case of Indonesia, its weak innovation capacity and low productivity cast doubt on this possibility.

4. Conclusion
The main way to ensure global food security in the 21st century is to improve agricultural efficiency. The evolution to Agriculture 5.0 requires the introduction of technologies, which will enable farmers to increase their productivity while reducing the environmental impact of agriculture and solving a number of important social and political problems of food systems.

However, persistent inequality among countries limits the ability to increase global production of quality and affordable food in the near future. The analysis shows that among the leading food producers, only Brazil can influence world food supply through productivity growth. Thus, digital transformation technologies are not a panacea for solving the problem of ensuring global food security.

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