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QUALITY MANAGEMENT AT ENTERPRISES OF AGRO-INDUSTRIAL COMPLEX (AIC) 4.0 AS THE BASIS OF THEIR DIGITAL COMPETITIVENESS

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A B S T R A C T

The purpose of the article is to determine the prospects for improving the practice of quality management of agricultural products at AIC 4.0 enterprises in order to increase their digital competitiveness in the world food markets in the conditions of the Fourth Industrial Revolution. Based on econometric modeling of international experience for 2022, it has been proved that quality (regression coefficient: 0.3673) contributes more (almost 6 times) to competitiveness than price (regression coefficient: 0.0622). It has also been revealed that the change in the quality and safety of food products by 71.57% is determined by the influence of AIC 4.0 technologies: market data (Big Data, AI, blockchain) and mobile banking; climate-smart agriculture technologies and innovative technologies (IoT, machine learning). A promising organizational scheme of quality management of agricultural products using AIC 4.0 technologies is presented on the example of the framework of the smart vertical farm of the Institute of Scientific Communications (ISC). The key conclusion is that quality management in the activities of agricultural enterprises using AIC 4.0 technologies forms the basis of their digital competitiveness in the conditions of the Fourth Industrial Revolution. The theoretical significance of the authors' conclusions lies in the fact that they have revealed the peculiarities of the organization of world food markets in the context of global digital competition. The practical significance of the article is due to the fact that it offers a promising scenario for strengthening the digital competitiveness of agricultural enterprises and advancing SDG2 in the "Decade of Action", as well as a set of authors' recommendations for the successful implementation of this scenario through improving food quality management based on the engineering of AIC 4.0 technologies.

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1. INTRODUCTION

The fight against global hunger is enshrined as a Sustainable Development Goal (SDG2) and therefore has strategic importance for humanity. International trade in world food markets makes an important contribution to achieving SDG2. From the standpoint of food importing countries, it is worth noting that many of them are characterized by an unfavorable natural and climatic environment for agriculture and therefore they experience a chronic shortage of food. The import of food products allows them to reduce the severity of the shortage of these products.

Food trade is also justified from the point of view of the international division of labor. In most cases, it is not profitable to grow all types of agricultural products that are in demand on local markets in own country. The import of the least profitable types of food products for agricultural production is economically efficient and therefore preferable. At the same time, in order to meet the needs of modern progressive society, it is necessary to export agricultural products that are highly competitive in the world food markets.

From the point of view of food exporting countries, it is worth paying attention to the fact that in order to fully utilize the production capacities of agricultural enterprises and benefit from “economies of scale”, they cannot be limited only to local markets, and therefore they need to export food products. For the fullest disclosure of the export potential of agricultural enterprises, their products must have high competitiveness in world markets. Unclaimed agricultural products are associated with high risks of losses for their producers, as they are perishable and may lose their consumer properties due to long storage in warehouses if it is impossible to sell them quickly.
Thus, the condition for the balance of world food markets and the practical implementation of SDG2 in the world economy is the production of agricultural products with high global competitiveness. The problem is that the Fourth Industrial Revolution brought radical changes in the nature of competition in world markets. Digital competition has emerged, which increasingly determines the position of participants in global economic relations on world markets. The peculiarities of the organization of world food markets in the context of global digital competition are poorly studied, which acts as a gap in the literature.

Before the onset of the Fourth Industrial Revolution, the quality was poorly differentiated among food products, which were mainly classified into fresh and spoiled (not subject to sale and consumption) food. Therefore, the price competitiveness of agricultural products almost completely determined its position in the world food markets.

The Fourth Industrial Revolution has opened up more opportunities to improve the quality of food products, which has become highly differentiated. Fresh food differs significantly among suppliers, and digital technologies of industry 4.0 help to best meet the growing requirements for the quality of food products. At the same time, the use of these technologies changes the attitude of agricultural enterprises to AIC 4.0 as a high-tech segment of the agricultural economy.

This article seeks to fill this gap in the literature and aims to determine the prospects for improving the practice of quality management of agricultural products at enterprises of AIC 4.0 in order to increase their digital competitiveness in the world food markets in the context of the Fourth Industrial Revolution.

The originality of the research carried out in this article is due to the fact that for the first time it draws a clear parallel between the traditional and digital competitiveness of agricultural enterprises in the world food markets, as well as between the low-tech and high-tech (based on AIC 4.0 technologies) approach to food quality management in the activities of these enterprises.

Further, in this article, the authors conduct a literature review and gap analysis. After that, experimental design and research methodology is revealed. Then, in the results section, three research tasks are solved sequentially: 1) determining the contribution of quality management at enterprises of AIC 4.0 to their digital competitiveness; 2) creating alternative scenarios for the digital competitiveness of enterprises of AIC 4.0 depending on the approach to quality management in the “Decade of Action”; 3) developing a quality management framework on the smart vertical farm of AIC 4.0 in order to increase digital competitiveness.

2. LITERATURE REVIEW AND GAP ANALYSIS

2.1 Digital competitiveness as a new type of global competitiveness of agricultural enterprises in the context of the fourth industrial revolution

The issues of international trade in agricultural products on world food markets are widely covered and discussed in detail in the available scientific literature (Abuzyarova, 2017; Koshta et al., 2021; Zolin et al., 2021). Scientists agree that the volume of exports of food products is the most important indicator of its global competitiveness (Litvinova et al., 2016; Sukhadolets et al., 2021). However, the causal relationships of the global competitiveness of agricultural enterprises in the conditions of the Fourth Industrial Revolution remain poorly understood, and their significant uncertainty is a gap in the literature. The identified gap raises the following research question:

RQ_1: What determines the global competitiveness of agricultural enterprises in the context of the Fourth Industrial Revolution?

In their works, M.Y. Ali et al. (2022), Bandoophanit and Pumprasert (2022), Kabir et al. (2021), Kim and Bhalla (2022) note that the global competitiveness of agricultural enterprises is affected by the price of food products sold by them, the reduction of which requires a reduction in its cost in order to increase competitiveness. This statement was most reliable prior to the beginning of the Fourth Industrial Revolution, when the quality of food was almost the same for all sellers in the market.

In the conditions of the Fourth Industrial Revolution, there is a technical possibility of producing food products with specified and improved nutritional properties: from increased nutritional value to a longer shelf life of food (Popkova, 2022a; Popkova and Sergi, 2023). The safety characteristics of food products also differ greatly in world markets: some sellers sell products with GMOs and various chemical additives, while others sell natural (organic) agricultural products (Aghazadeh et al., 2022; Radojevic et al., 2022).

Based on this literature, the H_1 hypothesis is put forward in this article that the global competitiveness of agricultural enterprises in the conditions of the Fourth Industrial Revolution determines the quality of their food products. To test the hypothesis, this article compares the impact of the price and quality of agricultural products on its global competitiveness (the volume of its exports).

2.2 The critical view of the existing approach to food product quality management at agricultural enterprises in the context of the fourth industrial revolution

The issues of measuring and managing the quality of food products are also disclosed in sufficient detail in the available scientific literature (Groot-Kormelinck et al., 2021; Novakovic et al., 2019). Nevertheless, the existing literature does not clarify the cause-and-effect relationships of changes in the quality of food products in the conditions of the Fourth Industrial Revolution, the uncertainty of which is a gap in the literature. The identified gap raises the following research question:
RQ_2: What determines the quality of food products?

Based on the experience of agricultural enterprises before the onset of the Fourth Industrial Revolution, the available literature identifies the following infrastructural factors of the quality of food products:

- supply chain infrastructure as a factor of supply chain optimization to accelerate the sale of products and prevent their spoilage in warehouses for logistical reasons (M.H. Ali et al., 2022; Mohib et al., 2023; Schmidt and Schmidt, 2019);
- irrigation infrastructure as a factor of increasing the climatic stability of agricultural production and reducing the natural and climatic risks of food quality (Sirimewan et al., 2023; Sirimewan et al., 2021);
- the infrastructure of organic agriculture as a factor in the rejection of GMOs and chemical additives in favor of the production of natural food products (Niewczas-Dobrowolska et al., 2019a; Shumka et al., 2021; Niewczas-Dobrowolska et al., 2019b).
- In the literature, revealing the latest advanced experience of food product quality management in the activities of agricultural enterprises, the following promising technologies of agro-industrial complex 4.0 are highlighted:
- market data (Big Data, AI, blockchain) and mobile banking, providing "smart" management of supply and distribution chains, as well as transparency of these chains and quality control of food products at all stages of these chains (Su et al., 2022; Wang et al., 2022);
- climate-smart agriculture technologies that guarantee the production of high-quality agricultural products, regardless of changes in the natural and climatic environment (Ifeanyi-Obi et al., 2022; Mangaza et al., 2021; Popkova, 2022b; Popkova, 2022c);
- innovative technologies (IoT, machine learning), allowing to automate agricultural production, thereby optimizing the growing conditions and care for each individual plant, which allows to produce food products with specified and improved nutritional properties (Matkovskaya et al., 2022; Sabden and Turginbayeva, 2017).

Based on this literature, the H_2 hypothesis is put forward in this article that the quality of food products in the conditions of the Fourth Industrial Revolution is largely determined by AIC 4.0 technologies. To test the hypothesis, the influence of factors of standard infrastructure and factors of AIC 4.0 technologies on the quality of agricultural products is compared in this article.

3. EXPERIMENTAL DESIGN AND RESEARCH METHODOLOGY

The search for answers to the posed RQs in the article is carried out using the econometric methodology. The research model has the following form:

$$\begin{cases} AgrTr=a_{AgrTr}+b_{AgrTr(FC)}*FC+b_{AgrTr(QS)}*QS; \\ QS=a_{QS}+b_{QS(md)}*md+b_{QS(si)}*si+b_{QS(cs)}*cs+ \\ +b_{QS(ii)}*ii+b_{QS(sa)}*sa+b_{QS(it)}*it, \end{cases} \quad (1)$$

where AgrTr – agricultural trade as an indicator of the global competitiveness of food products;
FC – change in average food costs;
QS – quality and safety;
md – access to market data and mobile banking;
si – supply chain infrastructure;
cs – early-warning measures / climate-smart agriculture;
ii – irrigation infrastructure;
sa – sustainable agriculture;
it – commitment to innovative technologies.

All dependent and factor variables in the model (1) are measured in points from 1 to 100 (best). The information and empirical base of this study is the official food security statistics for 2022 according to The Economist Impact (2023). The study sample included all 113 countries of the world for which food security statistics are kept and data are available in the materials of The Economist Impact (2023). The statistical base is given in the Microsoft Excel table attached to this article. Experimental design and research methodology are given in Table. 1.

Table 1. Experimental design and research methodology

RQ	Hypothesis	Research task	Method of solving the task	Condition for proving the hypothesis
RQ_1: What determines the global competitiveness of agro-industrial enterprises?	H_1: The global competitiveness of agro-industrial enterprises is determined by quality	Task 1: To determine the contribution of quality management at AIC 4.0 enterprises to their digital competitiveness	Regression analysis method	quality contributes more to competitiveness than price
RQ_2: What determines the quality of food products?	H_2: The quality of food products is determined by AIC 4.0 technologies.			AIC 4.0 technologies contribute more to quality than standard infrastructure
		Task 2: To create alternative scenarios for the digital competitiveness of enterprises of AIC 4.0, depending on the approach to quality management in the “Decade of Action”	Scenario analysis method	the scenario of intensive development of AIC 4.0 provides the greatest increase in quality
	-	Task 3: To develop a quality management framework on the smart vertical farm of AIC 4.0 in the interests of increasing digital competitiveness	Case study method	-

Source: developed by the authors.

As shown in Table 1, the article aims to achieve three tasks. The first task of this study is to determine the contribution of quality management at enterprises of AIC 4.0 to their digital competitiveness. To solve this task, the regression analysis method is used. Using the chosen method, the authors carry out econometric modeling of the dependence of the export of food products (“agricultural trade”, it will be denoted AgrTr) as an indicator of its global competitiveness on the factors of price (“change in average food costs”, it will be denoted FC) and quality (“quality and safety”, it will be denoted QS) of this product.

The hypothesis H_1 is considered proven if the regression coefficient for the quality factor is greater than the regression coefficient for the price factor ($b_{AgrTr(QS)}>b_{AgrTr(FC)}$). This means that quality contributes more to competitiveness than price. Using the regression analysis method, econometric modeling of the dependence of quality (QS) on the following factors is also carried out:

- access to market data and mobile banking (factor of AIC 4.0, it will be denoted as md) and supply chain infrastructure (it will be denoted as si) as alternative factors of supply chain management;
- early-warning measures / climate-smart agriculture (factor of AIC 4.0, it will be denoted as cs) and irrigation infrastructure (it will be denoted as ii) as alternative factors of management of climate-smart agriculture;
- sustainable agriculture (it will be denoted as sa) and commitment to innovative technologies (factor of AIC 4.0, it will be denoted as it) as alternative factors for the development of natural (organic) agriculture.

The H_2 hypothesis is recognized as proven if the regression coefficients for factor variables related to AIC 4.0 in most cases exceed the regression coefficients for factor variables related to standard infrastructure (bQS(md)>bQS(si) and/or bQS(cs)>bQS(ii) and/or bQS(it)>bQS(sa)). This means that AIC 4.0 technologies contribute more to quality than standard infrastructure. The economic sense of testing the H2 hypothesis is to prove the importance of AIC 4.0 technologies with the unconditional and continuing importance of standard infrastructure in the conditions of the Fourth Industrial Revolution.

The second task of the study is related to the creation of alternative scenarios for the digital competitiveness of enterprises of AIC 4.0, depending on the approach to quality management in the "Decade of Action". To solve this task, the method of scenario analysis is used. Using the chosen method, the values of factor variables corresponding to three alternative scenarios are substituted into the research model (1). All scenarios are made for the period of the "Decade of Action" (until 2030). The first scenario is to preserve the eight-year trend of quality and safety and agricultural trade. It assumes the preservation of the values of factor variables at the level of 2022, the influence of which on the dependent variables is not taken into account. The eight-year trend of quality and safety and agricultural trade are taken into account, the change of which in 2022 compared to 2016 is predicted for 2030 compared to 2022.

The second scenario is the preservation of the eight-year trend in the development of AIC 4.0. The second scenario is the preservation of the eight-year trend in the development of AIC 4.0. The eight-year trend of factor variables related to AIC 4.0 is taken into account: access to market data and mobile banking; early-warning measures / climate-smart agriculture; commitment to innovative technologies. Their change in 2022 in comparison with 2016 is predicted for 2030. In comparison with 2022, the predicted values of factor variables are substituted into the research model (1) - this is how the predicted values of the dependent variables are determined.

The third scenario of intensive development of AIC 4.0. To create it, the maximum values (100 points) of factor variables related to AIC 4.0 are taken: access to market data and mobile banking; early-warning measures / climate-smart agriculture; commitment to innovative technologies. The predicted values of factor variables are substituted into the research model (1) – this is how the predicted values of the dependent variables are determined.

Three alternative scenarios are compared according to the criterion of the magnitude of the change (projected growth) of the dependent variables: 1) quality and safety and 2) agricultural trade in 2030 compared to 2022.
The additional proof of the H_2 hypothesis is that the scenario of intensive development of AIC 4.0 provides the greatest increase in the quality and global competitiveness of food products.

The third task of this research is the development of a quality management framework on the smart vertical farm of AIC 4.0 in the interests of increasing digital competitiveness. This task is solved using the case study method, which reveals the unique and advanced experience of quality management at the smart vertical farm of the Institute of Scientific Communications (ISC) in the Sredneakhtubinsky District of the Volgograd Region (Russia) in 2022

4. RESULTS

4.1 Contribution of quality management at enterprises of AIC 4.0 to their digital competitiveness

As part of the solution of the first task of this study, which consists in determining the contribution of quality management at enterprises of AIC 4.0 to their digital competitiveness, we will conduct the factor analysis of the digital competitiveness of agro-industrial enterprises in the conditions of the Fourth Industrial Revolution (Table 1).

Table 1. Analysis of the dependence of agricultural trade on price and quality factors

Regression statistics						
Multiple R	0,5110					
R-Square	0,2611					
Adjusted R-Square	0,2476					
Standard Error	10,6097					
Observations	113					
ANOVA and Fischer's F-test						
	df	SS	MS	Observed F	Critical F	Significance F
Regression	2	4374,8828	2187,4414	19,4327	4,8035	$5,9*10^{-8}$
Residual	110	12382,1499	112,5650	Fischer's F-test is passed at a significance level of 0.01		
Total	112	16757,0327				
Regression model parameters and Student's t-test						
	Coeffi-cients	Standard Error	t-Stat	P-Value	Lower 95%	Upper 95%
Constant	39,0500	4,7439	8,2316	$4,2*10^{-13}$	29,6486	48,4513
FC	0,0622	0,0374	1,6642**	0,0989	-0,0119	0,1363
QS	0,3673	0,0767	4,7885*	0,0000	0,2153	0,5193

* Student's t-test was passed at a significance level of 0.01, where critical t=2.6204;
* Student's t-test was passed at a significance level of 0.10, where the critical t=1.6586;
Source: calculated and compiled by the authors.

The results from Table 1 indicate that the change in agricultural trade among the sample countries in 2022 by 51.10% (multiple R=0.5110, R2=0.2611) is explained by the influence of price and quality factors. Fischer's F-test was passed at a significance level of 0.01. For the factor variable QS, the Student's t-test was passed at the significance level of 0.01, where the critical t =2.6204, and for the variable FC – at the significance level of 0.10. Consequently, the error of relationship of agricultural trade with the factor variable QS (1%) is much less than with FC (10%).

The regression coefficient for the factor of quality is greater than the regression coefficient for the factor of price ($b_{AgrTr(QS)}>b_{AgrTr(FC)}$, 0,3673>0,0622). This means that quality contributes more to competitiveness than price and proves the H_1 hypothesis put forward. This makes it possible to exclude an insignificant variable – the price (FC) from further research in this article. The refined regression analysis of the dependence of agricultural trade on the key factor – quality and safety of food products – is carried out in Table 2.

Table 2. Refined analysis of the dependence of agricultural trade on the quality (including safety) of food products

Regression statistics						
Multiple R	0,49242					
R-Square	0,24247					
Adjusted R-Square	0,23565					
Standard Error	10,6939					
Observations	113					
ANOVA and Fischer's F-test						
	df	SS	MS	Observed F	Critical F	Signifi-cance F
Regression	1	4063,12	4063,12	35,5294	6,8688	$3*10^{-8}$
Residual	111	12693,9	114,36	Fischer's F-test is passed at a significance level of 0.01		
Total	112	16757				
Regression model parameters and Student's t-test						
	Coeffi-cients	Standard Error	t-Stat	P-Value	Lower 95%	Upper 95%
Constant	39,9804	4,74827	8,42	$1,5*10^{-13}$	30,5714	49,3895
QS	0,4199	0,0704	5,9606*	$3*10^{-8}$	0,2803	0,5594

* Student's t-test was passed at a significance level of 0.01, where critical t=2.6204.
Source: calculated and compiled by the authors.

Results from the Table 2 indicate that the change in agricultural trade among the sample countries in 2022 by 49.24% (multiple R=0.4924, R2=0.2425) is explained by the influence of the food quality factor. Fischer's F-test was passed at a significance level of 0.01. The Student's t-test was passed at a significance level of 0.01, where critical t=2.6204. Consequently, the error of the relationship between agricultural trade and the factor variable QS is minimal and does not exceed 1%. Conducted and successfully passed tests indicate the reliability of the results of regression analysis.
Now we will conduct the factor analysis of the quality of food products in the conditions of the Fourth Industrial Revolution. For this purpose, using the regression analysis method, econometric modeling of the quality dependence (QS) of a set of factors selected in the research model (1) was carried out (Table 3).

The results from Table 3 show that the change in the quality and safety of food products among the sample countries in 2022 by 82.36% (multiple R=0.8236, R2=0.6783) is explained by the influence of selected quality management factors. Fischer's F-test was passed at a significance level of 0.01.

The regression coefficient for factor si is greater than the regression coefficient for factor md. This leads to the conclusion that the standard supply chain infrastructure is the main one, but access to market data and mobile banking is also important for supply chain management in the context of the Fourth Industrial Revolution. For both factor variables (md and si), the Student's t-test was passed at a significance level of 0.01, where critical t=2.6204.

The regression coefficient for factor cs is greater than the regression coefficient for factor ii ($b_{QS(cs)}>b_{QS(ii)}$, 0,0108>-0,0019). This makes it possible to conclude that early-warning measures / climate-smart agriculture (the factor of AIC 4.0) is crucial for management of climate-smart agriculture in the conditions of the Fourth Industrial Revolution.

The regression coefficient for factor it is greater than the regression coefficient for factor sa ($b_{QS(it)}>b_{QS(sa)}$, 0,1007>0,0326). This allows us to conclude that commitment to innovative technologies (the factor of AIC 4.0) is crucial for the development of natural (organic) agriculture in the conditions of the Fourth Industrial Revolution. For the factor variable it, the Student's t-test was passed at a significance level of 0.01, where the critical t = 2.6204.

Consequently, the error in the relationship of quality and safety of food products with these factor variables is minimal and does not exceed 1%.

Table 3. Analysis of the dependence of food quality on standard market factors and on factors of AIC 4.0

Regression statistics						
Multiple R	0,8236					
R-Square	0,6783					
Adjusted R-Square	0,6601					
Standard Error	8,3639					
Observations	113					
ANOVA and Fischer's F-test						
	df	SS	MS	Observed F	Critical F	Significance F
Regression	6	15632,3428	2605,3905	37,2435	2,9768	5,5E-24
Residual	106	7415,2919	69,9556	Fischer's F-test is passed at a significance level of 0.01		
Total	112	23047,6347				
Regression model parameters and Student's t-test						
	Coefficients	Standard Error	t-Stat	P-Value	Lower 95%	Upper 95%
Constant	34,9164	2,6451	13,2003	0,0000	29,6722	40,1606
md	0,1217	0,0389	3,1257*	0,0023	0,0445	0,1990
si	0,3105	0,0511	6,0806*	$1{,}9*10^{-8}$	0,2093	0,4118
cs	0,0108	0,0201	0,5379	0,5918	-0,0291	0,0507
ii	-0,0019	0,0306	-0,0618	0,9508	-0,0627	0,0589
sa	0,0326	0,0275	1,1843	0,2389	-0,0220	0,0872
it	0,1007	0,0232	4,3326*	$3{,}4*10^{-5}$	0,0546	0,1467

* Student's t-test was passed at a significance level of 0.01, where critical t=2.6204.
Source: calculated and compiled by the authors.

Thus, the regression coefficients for factor variables related to AIC 4.0 in most cases exceed the regression coefficients for factor variables related to standard infrastructure, which means that AIC 4.0 technologies contribute more to quality than standard infrastructure and proves the hypothesis H_2. The refined analysis of the dependence of the quality and safety of food products on the factors of AIC 4.0 is carried out in Table 4.

Table 4. Refined analysis of the dependence of food quality on the factors of AIC 4.0

Regression statistics						
Multiple R	0,7157					
R-Square	0,5122					
Adjusted R-Square	0,4987					
Standard Error	10,1563					
Observations	113					
ANOVA and Fischer's F-test						
	df	SS	MS	Observed F	Critical F	Significance F
Regression	3	11804,1609	3934,7203	38,1452	3,9665	$6{,}2*10^{-17}$
Residual	109	11243,4738	103,1511	Fischer's F-test is passed at a significance level of 0.01		
Total	112	23047,6347				
Regression model parameters and Student's t-test						
	Coefficients	Standard Error	t-Stat	P-Value	Lower 95%	Upper 95%
Constant	38,0845	3,0713	12,4001	$1{,}48*10^{-22}$	31,9973	44,1718
md	0,2463	0,0415	5,9326*	$3{,}6*10^{-8}$	0,1640	0,3286
cs	0,0571	0,0225	2,5405**	0,0125	0,0126	0,1017
it	0,1627	0,0251	6,4889*	$2{,}6*10^{-9}$	0,1130	0,2124

* Student's t-test was passed at a significance level of 0.01, where critical t=2.6204;
* Student's t-test was passed at a significance level of 0.05, where the critical t=1.9814;
Source: calculated and compiled by the authors.

The results from Table 4 indicate that the change in the quality and safety of food products among the sample countries in 2022 by 71.57% (multiple R=0.7157, R2=0.5122) is explained by the influence of a combination of three considered factors of AIC 4.0. Fischer's F-test was passed at a significance level of 0.01. For the factor variables md and it, Student's t-test was passed at a significance level of 0.01, where critical t=2.6204. For the factor variable cs, Student's t-test was passed at a significance level of 0.05, where critical t=1.9814.

Consequently, the error of relationship of quality and safety of food products with access to market data and mobile banking, as well as with commitment to innovative technologies is minimal and does not exceed 1%, and with early-warning measures / climate-smart agriculture is also quite small and does not exceed 5%.

Conducted and successfully passed tests indicate the reliability of the results of regression analysis. The results obtained make it possible to refine the research model (1) and present it as the following system of regression equations:

$$\begin{cases} AgrTr=39,9804+0,4199*QS; \\ QS=38,0845+0,2463*md+0,0571*cs+0,1627*it. \end{cases} \quad (2)$$

The econometric model (2) means that agricultural trade as an indicator of the global competitiveness of food products rises by 0.4199 points with an increase in the quality and safety of food products by 1 point. In turn, the quality and safety of food products increases by 0.2463 points with an increase in access to market data and mobile banking by 1 point. The quality and safety of food products increases by 0.0571 points with the growth of early-warning measures / climate-smart agriculture by 1 point. The quality and safety of food products rises by 0.1627 points with the growth of commitment to innovative technologies by 1 point.

Summarizing the results obtained in the course of solving the first task, we can conclude that in the conditions of the Fourth Industrial Revolution, the conjuncture of world food markets is undergoing profound changes. The first of these changes is due to the fact that the price of food ceases to play a primary role in the global competitiveness of agricultural products, recedes into the background, giving way to the quality and safety of food. The second change is that AIC 4.0 technologies are becoming increasingly important, with the unconditional and continuing importance of standard infrastructure in quality and safety management of food products.

4.2 Scenarios of digital competitiveness of enterprises of AIC 4.0 depending on the approach to quality management in the "decade of action"

As part of the solution of the second task of this study, the values of factor variables corresponding to three alternative scenarios were substituted into the research model (2) in order to develop alternative scenarios for the digital competitiveness of enterprises of AIC 4.0, depending on the approach to quality management in the "Decade of Action". All scenarios are made for the period of the "Decade of Action" (until 2030) and are illustrated in Fig. 1.

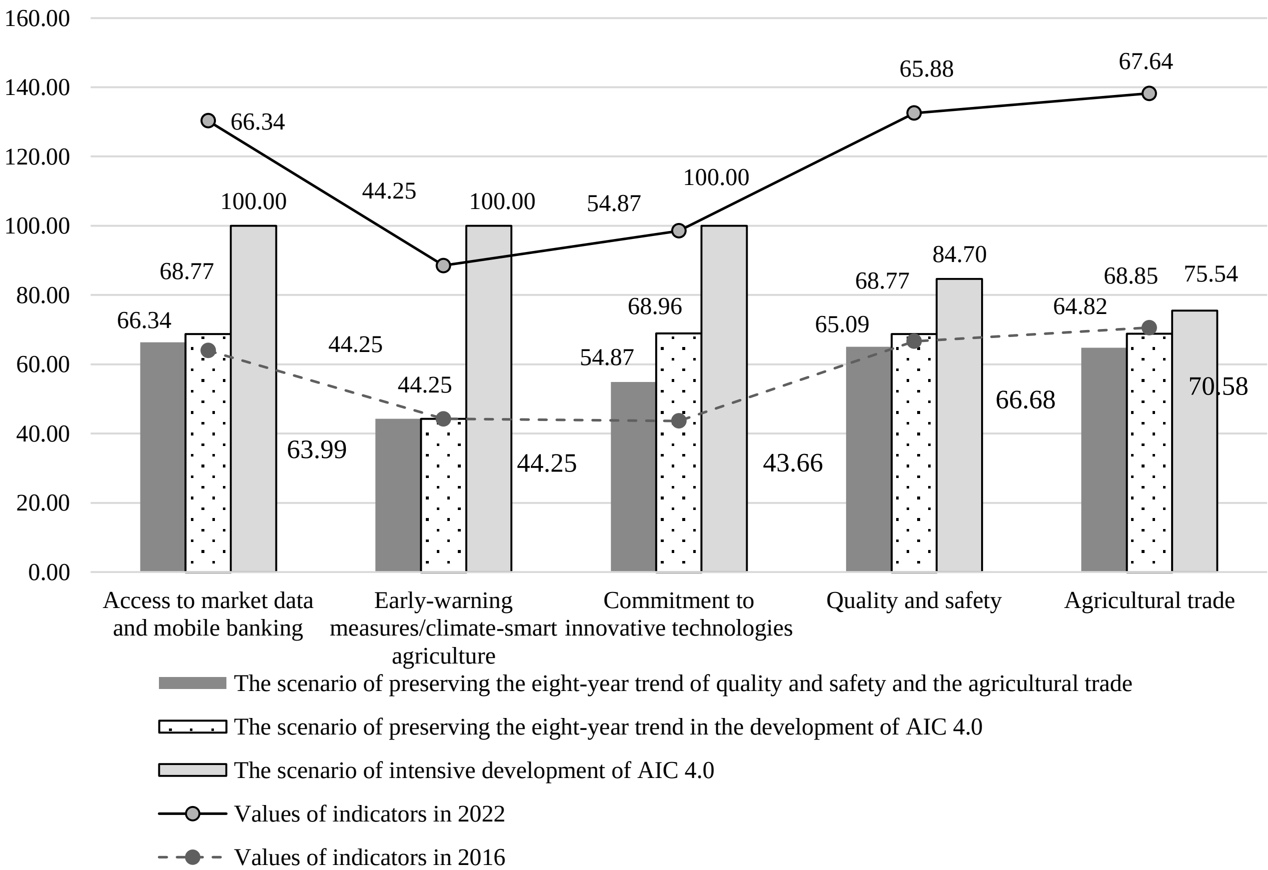

Figure 1. Alternative scenarios of digital competitiveness of enterprises of AIC 4.0 depending on the approach to quality management

Source: Calculated and constructed by the authors.

The first scenario assumes the preservation of the eight-year trend of quality and safety and the agricultural trade. In 2022, the average quality and safety of food products in the sample of countries was 65.88 points, while in 2016 it was 66.68 points. That is, the eight-year trend was -1.20%. In 2022, agricultural trade averaged 67.64 points in the sample of countries, while in 2016 it was 70.58 points. That is, the eight-year trend was -4.17%.

If the identified eight-year trend continues, that is, with a reduction in the “Decade of Action” by 1.20% and 4.17%, respectively, the quality and safety of food products will decrease to 65.09 points by 2030, and agricultural trade - to 64.82 points. This will become a serious obstacle to the implementation of SDG2, which will not be achieved according to the scenario under consideration.

The second scenario assumes the preservation of the eight-year trend in the development of AIC 4.0. In 2022, access to market data and mobile banking averaged 66.34 points in a sample of countries, while in 2016 it was 63.99 points. That is, the eight-year trend was 3.67%. In 2022, early-warning measures / climate-smart agriculture averaged 44.25 points in the sample of countries, as well as in 2016. That is, the eight-year trend was 0%. In 2022, commitment to innovative technologies averaged 54.87 points in a sample of countries, while in 2016 it was 43.66 points. That is, the eight-year trend was 25.68%.

If the identified eight-year trend continues, that is, with an increase in the “Decade of Action” by 3.67%, 0% and 25.68%, respectively, access to market data and mobile banking will reach 68.77 points by 2030, early-warning measures / climate-smart agriculture will remain at 44.25 points, and commitment to innovative technologies will increase up to 68.96 points. When substituting the predicted values of factor variables into model (2), it has been revealed that according to the scenario under consideration, the quality and safety of food products will increase to 68.77 points (+4.39%) by 2030, and agricultural trade – to 68.85 points (+1.79%).
The third scenario assumes intensive development of AIC 4.0. To develop it, the maximum values (100 points) of factor variables related to AIC 4.0 were taken: access to market data and mobile banking; early-warning measures / climate-smart agriculture; commitment to innovative technologies. When substituting the predicted values of factor variables into model (2), it has been revealed that according to the scenario under consideration, the quality and safety of food products will increase to 84.70 points by 2030, and agricultural trade – to 75.54 points. The recommended increase in the indicators for the development of agro-industrial complex 4.0 and the projected increase in the quality and competitiveness of food is reflected in Fig. 2.

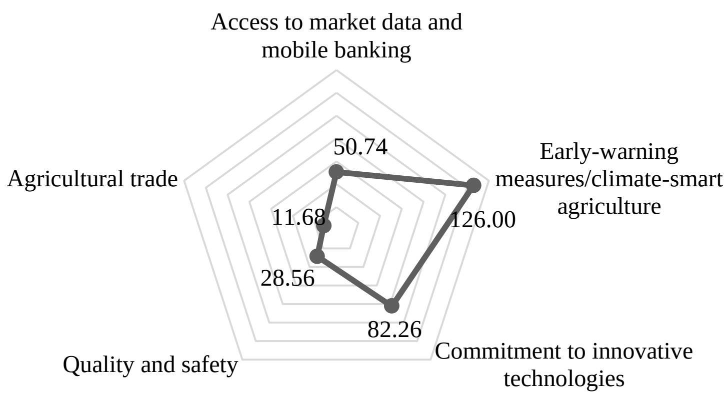

Figure 2. Recommended increase in indicators for the development of AIC 4.0 and the projected increase in the quality and competitiveness of food, %
Source: Calculated and constructed by the authors.

For the practical implementation of the third scenario, the following increase in indicators for the development of AIC 4.0 is recommended: access to market data and mobile banking by 50.74%, early-warning measures / climate–smart agriculture – by 126%, commitment to innovative technologies - by 82.26%. Thanks to this, the quality and safety of food products will increase by +28.56% by 2030, and agricultural trade – by 11.68%.

Summarizing the results obtained during the solution of the second task, we can conclude that among the three alternative scenarios considered, the scenario of intensive development of AIC 4.0 is the most promising and preferable, since it provides the greatest increase in the quality and global competitiveness of food products. This is an additional proof of the H_2 hypothesis.

4.3 Quality management framework for the smart vertical farm AIC 4.0 to strengthen digital competitiveness

As part of the solution of the third task of this study, the case study method was used to develop a quality management framework for the smart vertical farm of AIC 4.0 to strengthen digital competitiveness. Using this method, the unique and advanced case experience of quality management at the smart vertical farm of the Institute of Scientific Communications (ISC) in the Sredneakhtubinsky district of the Volgograd region (Russia) in 2022 has been revealed (Fig. 3).

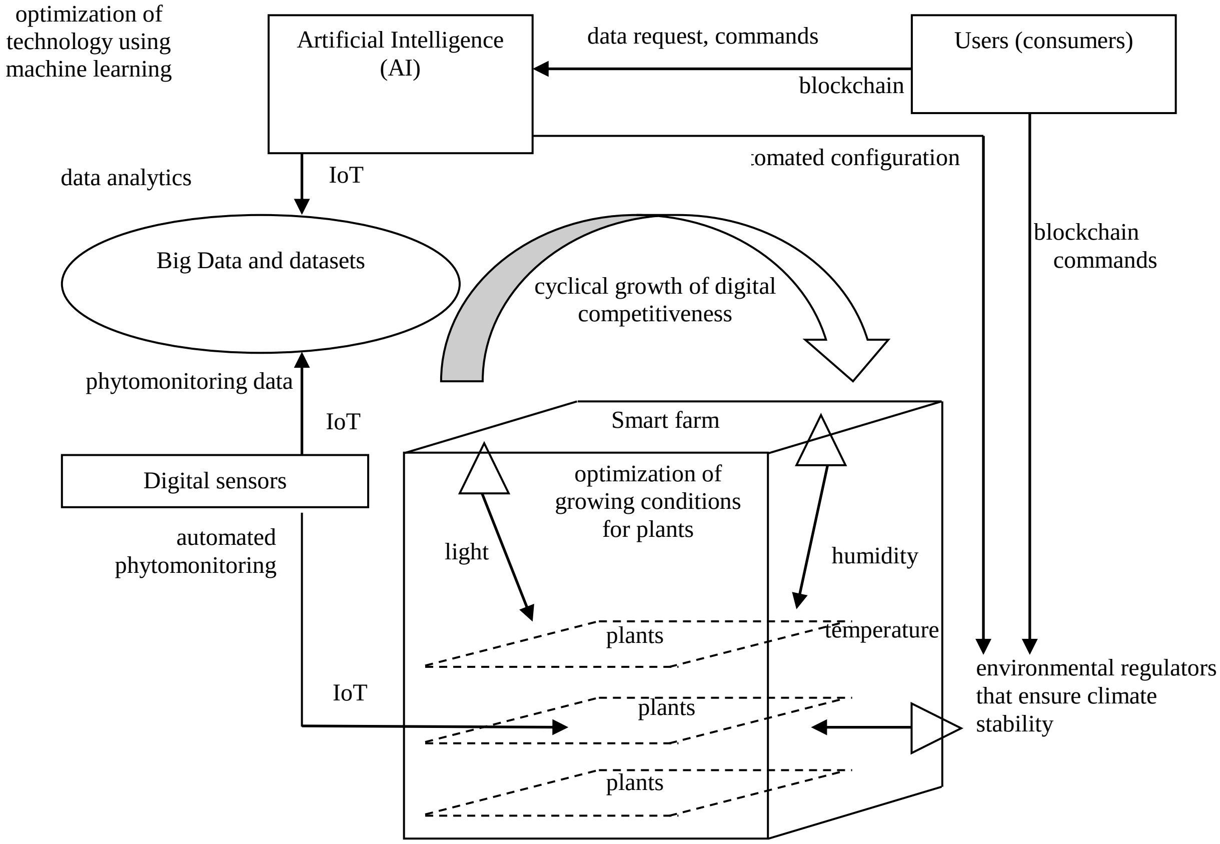

Figure 3. Quality management scheme at the smart vertical farm of AIC 4.0 in the ISC's framework
Source: developed by the authors.

As can be seen in Fig. 3, the smart vertical farm of ISC is equipped with a system of digital environmental regulators. These regulators ensure the climatic stability of the farm by adjusting light, humidity, temperature, watering plants, fertilizing and other parameters of plant care. The patented digital sensors developed by ISC ("Photons") carry out automated phytomonitoring via the Internet of Things (IoT).

Phytomonitoring data is transferred via IoT to the knowledge system of a smart farm, combined into Big Data and datasets. Artificial Intelligence (AI) conducts analytics of Big Data and datasets. The results of analytics make it possible to continuously optimize the technology of growing plants using machine learning. Taking into account the current technology, AI performs automated configuration of digital regulators of the growing environment in a smart vertical farm.

The quality management scheme on the smart vertical farm of AIC 4.0 in the ISC's framework also involves the participation of people. Since the ISC's farm is a scientific experimental platform, the people engaged in it are collective users-researchers from different universities of Russia participating in experiments. At a commercial farm, these can be consumers, but with limited rights (they only deal with control, without requesting data from AI and without participating in management). Users request data and transmit commands to AI via the blockchain, through which commands are also transmitted to digital regulators.
The advantage of the "smart" organization of the vertical farm in the ISC's framework based on AIC 4.0 technologies is the high efficiency of quality management - the production of agricultural products with specified and improved nutritional properties, as well as the guarantee of food safety. Due to this, the cyclical growth of the digital competitiveness of agricultural products grown at the smart farm is achieved.

5. DISCUSSION

The article contributes to the literature on the topic of engineering of AIC 4.0 technologies by substantiating the importance of these technologies to ensure the digital competitiveness of agricultural products in the conditions of the Fourth Industrial Revolution. The received answers to RQs in comparison with the existing literature are presented in Table 5.

As shown in Table 5, the scientific novelty of the research conducted in this article lies, firstly, in the fact that a new answer to RQ_1 has been obtained. Unlike M.Y. Ali et al. (2022), Bandoophanit and Pumprasert (2022), Kabir et al. (2021), Kim and Bhalla (2022), it has been proved that the global competitiveness of agro-industrial enterprises is not determined by price, but by the quality of food products, and the increase of the latter justifies the increase in cost and price.

Table 5. Received answers to RQs in comparison with the existing literature

Research question (RQ)	Answers presented in the existing literature	New answers received in the article taking into account the context of the Fourth Industrial Revolution
RQ_1: What determines the global competitiveness of agro-industrial enterprises?	by the price of food products, the reduction of which requires a reduction in its cost in order to increase competitiveness (M.Y. Ali et al., 2022; Bandoophanit and Pumprasert, 2022; Kabir et al., 2021; Kim and Bhalla (2022)	the quality of food products, the improvement of which justifies the increase in cost and price
RQ_2: What determines the quality of food products?	infrastructure support of agro-industrial enterprises: supply chain infrastructure (M.H. Ali et al., 2022; Mohib et al., 2023; Schmidt and Schmidt, 2019), irrigation infrastructure (Sirimewan et al., 2023; Sirimewan et al., 2021), infrastructure of organic agriculture (Niewczas-Dobrowolska et al., 2019a; Shumka et al., 2021; Niewczas-Dobrowolska et al., 2019b)	agro-industrial complex 4.0 technologies: market data (Big data, AI, blockchain) and mobile banking, climate-smart agriculture technologies, innovative technologies (IoT, machine learning)

Source: developed by the authors.

Secondly, a new response to RQ_2 has been received. It has proved that the quality of food products is not determined by the infrastructure of agro-industrial enterprises: supply chain infrastructure (unlike M.H. Ali et al., 2022; Mohib et al., 2023; Schmidt and Schmidt, 2019), irrigation infrastructure (unlike Sirimewan et al., 2023; Sirimewan et al., 2021) and the infrastructure of organic agriculture (in contrast to Niewczas-Dobrowolska et al., 2019a; Shumka et al., 2021; Niewczas-Dobrowolska et al., 2019b), but by AIC 4.0 technologies.

Among the most promising technologies: market data (Big Data, AI, blockchain) and mobile banking (which strengthened the evidence base of Su et al., 2022; Wang et al., 2022); climate-smart agriculture technologies (which strengthened the evidence base of Ifeanyi-Obi et al., 2022; Mangaza et al., 2021; Popkova, 2022b; Popkova, 2022c); innovative technologies (IoT, machine learning) (which strengthened the evidence base of Matkovskaya et al., 2022; Sabden and Turginbayeva, 2017).

6. CONCLUSION

So, the key conclusion based on the results of the study is that quality management in the activities of agricultural enterprises based on AIC 4.0 technologies forms the basis of their digital competitiveness in the conditions of the Fourth Industrial Revolution. Using econometric modeling of international experience for 2022, it has been proved that quality (regression coefficient: 0.3673) contributes more (almost 6 times) to competitiveness than price (regression coefficient: 0.0622).

It has also been revealed that the change in the quality and safety of food products by 71.57% is determined by the influence of AIC 4.0 technologies: 1) market data (Big Data, AI, blockchain) and mobile banking; 2) climate-smart agriculture technologies and 3) innovative technologies (IoT, machine learning). The promising organizational scheme for managing the quality of agricultural products using AIC 4.0 technologies has been presented on the example of the smart vertical farm of the ISC’s framework.

The theoretical significance of the authors’ conclusions lies in the fact that they have revealed the peculiarities of the organization of world food markets in the context of global digital competition. The first peculiarity: the price of food ceases to play a primary role in the global competitiveness of agricultural products; it recedes into the background, giving way to the quality and safety of food. The second peculiarity: AIC 4.0 technologies are becoming increasingly important with the unconditional and continuing importance of standard infrastructure in the quality and safety management of food products.

The practical significance of the article is related to the fact that it offers a promising scenario for strengthening the digital competitiveness of agricultural enterprises and advancing SDG2 in the “Decade of Action”, as well as a set of authors’ recommendations for the successful implementation of this scenario through the improvement of food product quality management based on the engineering of AIC 4.0 technologies. The quality management framework at the ISC's smart vertical farm can be useful for other enterprises of AIC 4.0 from different countries, and its implementation will help to increase their digital competitiveness.

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