

INTEGRATED QUALITY CHAIN FOR AGRICULTURAL PRODUCTS AND FOOD SECURITY BASED ON BEST PRACTICES OF QUALITY MANAGEMENT

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A B S T R A C T

The research focuses on food safety, traceability, and the post-harvest quality chain. The research is devoted to developing a technical approach to ensuring the sustainable development of the agricultural economy and food security based on advanced agricultural quality management methods using industrial and manufacturing engineering. To this end, it reviews advanced international experience based on SDG 2 implementation reports, FAOSTAT statistics, and empirical data from ISO, the WTO, and the Global Food Safety Initiative, and analyzes the latest achievements in industrial and manufacturing engineering for agricultural product quality at smart vertical farms. The novelty of the authors' approach lies in the systemic application of advanced agricultural quality management methods (intelligent sensors, blockchain, big data analytics, and the IoT) in combination with industrial and manufacturing engineering, making it possible to achieve more sustainable development of the agricultural economy and strengthen food security. Simple calculations based on data on the operation of these systems, including the number of failures, measurement ranges, and stability of operating conditions, make it possible to assess the operational characteristics of agricultural engineering infrastructure. The focus is on digital and automated quality assurance mechanisms, including sensor systems, data-driven monitoring, smart equipment, and algorithmic management of production parameters



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1. INTRODUCTION

Industrial and manufacturing engineering has become firmly established in the practice of smart and climate-resilient agriculture and is applied to achieve highly

productive organic agricultural production. Simultaneously, the quality of these products remains a secondary outcome of smart farming activities rather than an independent object of such engineering.

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This creates a pressing scientific and practical problem: because engineering and technical support are focused primarily on the productivity of smart farms and do not extend to the quality of agricultural products, this quality remains insufficiently predictable and demonstrates only marginal improvements.

The established approach to quality management in smart agriculture does not fully ensure the sustainable development of the agricultural economy and food security because it treats quality as secondary to productivity and focuses on compliance with existing quality standards rather than on achieving quality levels that exceed those standards.

The agrarian economy plays one of the most important roles in the global food system. It ensures the production of most of the food in the world and serves as the basis for social and economic stability. Given the critical value of food for life activities of humanity, the issue of its quality, which is realized through the processes of standardization and harmonization of production processes, acquires a special relevance (World Bank, 2025; FAO, 2025). In the modern conditions of globalization and digital transformation, there is a very acute need for integrating the international standards of quality management into the practice of activities of a larger number of agricultural producers and other subjects of the agrarian economy. These actions allow raising the level of safety and quality of food products, contribute to traceability in supply chains, and create conditions for the integration of agricultural companies into world markets.

An important tool that allows for the effective application of standards in agricultural companies' activities is the best practices of quality management. They directly influence labor productivity, safety of food production, and sustainability of the corresponding ecosystems. Depending on the character of these practices, they solve the problems of the quality of incoming resources, reduce transaction risks and costs, contribute to the restoration of soils, improve the capabilities of management systems in measurability and transparency of production, ensure a higher level of resource efficiency, and stimulate an increase in the level of the agrarian economy's sustainability.

Transition to a sustainable economy is one of the main challenges of the global food system. Production of healthy, nutritious, and safe food, combined with the high level of economic effectiveness of production and distribution systems, determines the current goals of scientific research and establishes the main principles for all participants of the agri-food system. According to this, scientific justification for the directions and possibilities of sustainable development of the agrarian economy and food security from the position of using best practices of quality management in agriculture acquires critical importance from the position of balancing the interests of

agricultural producers and achieving economic results against the background of environmental sustainability, social justice, and technological progress.

The research proposes an original solution to the identified problem by establishing independent engineering and technical support for improving the quality of agricultural products, separate from productivity engineering in agriculture, and enabling the advanced capabilities of digitalization to be used for the targeted and maximum enhancement of product quality. In view of the above, the research aims to develop a technical approach to ensuring the sustainable development of the agricultural economy and food security based on advanced agricultural quality management methods using industrial and manufacturing engineering. For this purpose, the article examines post-harvest quality, traceability, and food safety.

2. METHODOLOGY OF THE EXPERIMENTAL STUDY

From a fundamental perspective, the study conducted in this article is based on the scientific principles of the theoretical concept of industrial and manufacturing engineering in smart agricultural production presented in the literature by Meng et al. (2026), Parihar et al. (2026), Silva et al. (2026), and Zhang (2026). Within this concept, primary attention is given to increasing the productivity of smart farms, which is the primary focus of automation and engineering efforts. Simultaneously, the topic of industrial and manufacturing engineering for agricultural product quality remains insufficiently developed in the existing literature, constituting a research gap and limiting the application of this type of engineering to improve product quality.

The essence of the existing approach to quality management in smart agriculture is explained in the publications of Filintas A. (2025), Mehmood et al. (2026), Purohit and Yogi (2025), and Xu et al. (2026). It consists of optimizing the organizational processes of climate-resilient farms, including standardization, certification, quality control, sorting, and rejection of agricultural products, as well as their labeling and packaging; therefore, this approach can be described as organizational. A limitation of the established approach is the limited use of digital technologies and the absence of industrial and manufacturing engineering for agricultural product quality.

The research methodology within the studied problems has a complex character, which stems from the need to use theoretical provisions, methodological approaches, and tools that belong to different spheres of scientific cognition. The methodological basis of this paper is determined by the system approach. It allows viewing quality management as a multi-level mechanism, identifying cause-and-effect relationships between the best practices of quality management and sustainable

development of the agrarian economy and food security, and forms the possibility to study the cumulative effectiveness of the production system, which is manifested through control over the parameters of products and growth of adaptability to market conditions. The main provisions of the paper are viewed through the lens of the concept of sustainable development, which integrates economic, environmental, and social components of agricultural production effectiveness. This concept allows treating quality management from the position of long-term sustainability of agri-food systems, which is achieved in the conditions of climate change, environmental degradation, and technological transformation. The institutional approach was used to study and generalize the influence of regulatory and legal tools and mechanisms of standardization and certification on the parameters of the agrarian economy development and support of food security. It coordinates all levels of institutional sources of quality management, including the systems of standards of ISO, GLOBAL G.A.P., GFSI, etc., and determines the conditions and principles of formation of the best practices of quality management and food safety in the sphere of agricultural production. The process approach allowed studying the mechanisms of transformation of regulatory demands into specific operational practices, which are used at different stages of the formation of food products' value. The concept of quality management determines the theoretical foundation of understanding quality in the agrarian sector as a complex notion, which involves not only correspondence to standards but also safety, nutrition, satisfaction of consumer needs, environmental footprint, and social value.

The methodology of this research contains a range of general scientific and special methods, which allow for a comprehensive study of the paper's problems. Thus, the methods of theoretical generalization and systematization allowed forming the conceptual foundations of quality management in the agrarian sector, revealing its multidimensional nature, and developing a holistic system concept that is based on implementing best practices of quality management; structural and functional analysis allowed classification of the best practices of quality management by directions, the method of comparative analysis contributed to the study of the institutional architecture of the global system of standardization and identification of interconnections between them; content analysis of scientific publications and international reports ensures the possibility to reveal the global trends, risks, and challenges in the sphere of agrarian production; the logical and analytical method helped establish the cause-and-effect relationships between quality management and key results of agrarian economy's functioning; the method of synthesis allowed forming a generalized idea of the best practices of quality management as a complex approach to systematization and standardization of production.

Analysis of scientific publications on the issues of sustainable development of the agrarian economy and food security through implementing the best practices of quality management covers several interconnected research directions. They are concerned with global challenges of the modern agrarian sector, institutional mechanisms of standardization, innovative approaches to quality management of food, digital transformation of agricultural production, and eco-oriented practices of land use. Scientific discourse demonstrates an increasing realization of the fact that support of food security in the conditions of climate change requires not fragmentary improvements but a systemic reconfiguration of agri-food chains based on scientifically justified standards of quality.

Fundamental challenges of the modern agrarian economy are documented by international organizations and research institutions (IPBES, 2018; IPCC, 2023; FAO, 2020; FAOSTAT, 2024; FAOSTAT, 2025; World Bank, 2025). The institutional architecture of quality management systems in the agri-food spheres is viewed by researchers as a multi-level construct, which combines international standards, industry protocols, and operational practices. It was studied from the position of the following aspects: global influence of the Global Food Safety Initiative on harmonization of the standards of food products safety (Crandall et al., 2017), disclosure of practical aspects of implementation of HACCP with other tools of quality management (Lee et al., 2021), systematization of the quality management practice in sustainable food networks with the focus on the need for integration of economic, environmental, and social parameters of assessing the effectiveness of supply chains (Burgess et al., 2023), and determination of the methodological basis for implementing standards at the level of primary production given the entire range, from preparation of soil to post-harvest processing (Global G.A.P., 2020; USDA, n.d.).

The best agrarian practices, as the basis for ensuring the quality of food, were studied through the lens of their adaptability to different agricultural and environmental conditions. The interconnection between proper agricultural practices, traceability, and precise farming is substantiated (De Baerdemaeker & Saeys, 2015), the problem of unequal access of small farms to quality production resources, which forms a structural barrier to implementing the best practices is revealed (Michelson et al., 2023), and methodology of visual and instrumental assessment of the influence of agricultural practices on the quality of soil is offered, which creates the basis for justified decision-making on land use, is proposed (Alaoui et al., 2020; Al-Shammary et al., 2024).

Digital transformation of the agricultural sector is viewed as a driver of transition to proactive models of quality management, which is based on the systematization of achievements of Industry 4.0 in the sphere of quality

management of food, with emphasis on the key role of big data analytics, machine learning, and automatized control systems (Peres et al., 2025); it is manifested through application of corporate information systems based on machine learning for quality management in the conditions of agriculture that is adapted to climate (Osmonalieva et al., 2025) and realized through integration of the Internet of Things and automatized technologies for continuous monitoring of the growth of crops in the systems of precise farming (Vishwas et al., 2025). International specifics of implementing smart technologies in agrarian production are offered, and the issue of coordination of technological solutions with socioeconomic conditions of specific regions is indicated (Sozinova et al., 2022; Petrenko et al., 2019).

Financial & economic and institutional mechanisms of supporting high-quality transformation of the agrarian sector were studied through the lens of innovative systems and green finance, in particular, by revealing the prospects of green financing as a tool for stimulation of environmentally responsible food production (Kantor et al., 2023), using the DEA method to assess the effectiveness of regional innovative systems (Vechkinzova et al., 2019), applying innovative tools of government support of agri-food complex in the conditions of the digital economy (Bogoviz et al., 2018), and disclosing the role of deep learning and improvement of irrigation systems to ensure food security in emerging economies (Burkhanov et al., 2024)

Generalization of the scientific works showed that the study of the best practices of quality management in the agrarian economy is characterized by a high level of differentiation by subject spheres: technological, institutional, environmental, and economic. At the same time, there is a deficit of integrated conceptual models, which would systemically combine the regulatory and organizational, technological, environmental, social, and institutional aspects of quality management from the standpoint of their joint influence on the sustainability of the agrarian economy and food security. The existing studies rarely elaborate on the mechanisms of mutual strengthening of different categories of best practices, limiting themselves to the analysis of individual tools or directions. This leads to the necessity for the formation of a comprehensive concept that would demonstrate a synergetic effect from the complex implementation of best practices of quality management to achieve long-term sustainability of agri-food systems in the dynamic global environment.

The research objective was to develop a scientific view of the problem of sustainable development of the agrarian economy and food security based on implementing the best practices of quality management in agriculture, which takes place in the conditions of global challenges, climate change, and active technological development. To achieve this goal, it was necessary to solve a range of tasks concerning the identification of main challenges

peculiar to the agrarian economy at the modern stage, disclosure of the conceptual foundations of quality management through the lens of multidimensional nature of quality and its specifics in the sphere of agriculture, the study of the institutional architecture of the global system of standardization and best practices of quality management, classification of the best practices of quality management, and substantiation of their effect on the sustainability of the agrarian economy.

Drawing on the published literature by Juraev et al. (2024), Senthilkumaran et al. (2025), Song et al. (2024), and Wang et al. (2024), which identifies individual indications of improvements in agricultural product quality associated with the use of engineering and technical support tools in smart agriculture, this article advances the hypothesis that a substantial and clearly observable improvement in agricultural product quality in smart agricultural production can be achieved through the direct application of industrial and manufacturing engineering to quality management.

3. RESULTS

3.1 Engineering of Agricultural Product Quality at Smart Vertical Farms

To test the proposed hypothesis, we examine the latest achievements in international practice in the industrial and manufacturing engineering of agricultural product quality at smart vertical farms and assess their contribution to the sustainable development of the agricultural economy and food security.

The agrarian economy is the main element of the global food system, whose task is to provide food to over eight billion people. Agriculture plays the main role in the achievement of the Sustainable Development Goals, in particular, SDG 2 – Zero Hunger. Apart from its strategic role, connected with the food needs of humanity, it is also an important factor in employment and spatial dispersal. According to this, as of 2023, approximately 1 billion people (more than 26% of all employed) worked in the agrarian sector, including forestry and fishery (FAOSTAT, 2025), and the share of agricultural land in the total area of land was almost 37% (Trading Economics, 2025). Despite the scale and value of the sector, it faces large risks and challenges, connected with climate factors, macroeconomic proportions, and technological, environmental, and social processes. Different processes take place under the influence of these factors. They determine the volume and quality of production of food products and influence the sector's sustainability and the general development of humanity. Climate factors have the main effect on agrarian ecosystems. The conditions and duration of the vegetation period, the volume of precipitation, and the nutrition through the soil are the main conditions of growth and development of plants. At present, an increase in the global temperature, a change in rainfall

patterns, and an increase in the number of extreme weather events lead to a reduction in yield. These risks are especially acute for small farmers, who provide up to 70% of all food production in the world (IPCC, 2023). Against the background of the above risks, additional pressure on the agri-food system comes from economic fluctuations and structural changes in the markets. This leads to reduced possibilities to forecast company revenues, assess their risks, and ensure the accessibility of food of proper quality.

Digital transformation is a factor of adaptation to new conditions. Its tools determine the directions and reserves for further development of the sector. Thus, the Internet of Things allows ensuring traceability of production and food storage and sales; data analytics and automated systems of quality management raise the level of certainty during decision-making; cloud technologies contribute to better remote management of processes in the conditions of spatial dispersal. In aggregate, digital tools form new mechanisms of quality management and strengthen current ones due to an increase in the speed and volumes of information processes, access to processes that were not previously subject to influence, and integration of traditional agricultural technologies with digital ones.

Here, attention should be paid to systemic dysfunctions of the modern agricultural sector, which predetermine the general reduction in product quality, which takes place due to a technological gap between high-tech and traditional agricultural producers, low rates of agrarian infrastructure upgrades, fragmentation of quality management systems, an increase in environmental degradation of agricultural ecosystems, and violation of social standards. Agrarian companies find themselves in a low-productivity trap. Because of it, a low level of profitability does not allow for large investments in production upgrade, which, in turn, leads to a decrease in the profitability of the business, etc.

The low level of standardization of agricultural producers limits the ability to form global value chains based on harmonized standards and certification systems (ISO 22000, FSSC 22000, GLOBAL G.A.P.). Thus, the level of the chain traceability is reduced, and the risks of contamination of the product with pathogens grow. These processes, in turn, lead to the possibility of quick dissemination of diseases or infections, decrease the quality of food, and reduce economic results.

Another important factor that negatively influences the quantitative and qualitative indicators of agricultural production is the general environmental degradation, caused by intensive methods of modern agricultural production. Due to this, 10–15 million hectares of arable land are lost annually (IPBES, 2018). Also, agriculture consumes almost 70% of fresh water (FAO, 2020), and agri-food systems account for approximately 30% of greenhouse gas emissions (FAOSTAT, 2024).

The notion of quality in the agrarian sector of the economy has a special meaning. It is treated not only through the lens of meeting consumer demands or competitiveness but also from the position of strategic effectiveness. According to this, quality covers a totality of processes aimed at correspondence to standards, safety, and satisfaction of consumer needs, with simultaneous achievement of economic, environmental, and social effectiveness. Quality management is a holistic mechanism of raising the effectiveness of the use of resources, reducing risks and losses, and forming an environment of trust and confidence. In this context, institutionalized systems of quality management based on ISO 9001, HACCP, etc. contribute to the optimization of agricultural production, which is achieved due to the process approach, monitoring of critical checkpoints, and continuous improvement.

From the standpoint of the market economy, quality management is one of the key factors in raising competitiveness. This is supported by compliance with the international standards of quality and safety, among which are Codex Alimentarius, ISO, WTO-SPS, and others. Correspondence to these norms ensures access to global markets and is a factor of integration into the world food system. The connection between quality management and effective use of resources, which is based on standards of environmental management ISO 14001, EMAS, and innovative methods of control of the quality of soil, seeds, fertilizers, irrigation, etc., contributes to an increase in productivity due to rational use of resources.

From the position of food security, quality is assigned the main role in the affordability of food, its nutritional value, stability of supply, and safety. Therefore, drawbacks in management at any stage of the supply chain in the system of the agrarian economy can negatively influence each of the above parameters. Thus, the loss of product volumes, reduction in their nutritional value, or danger to health can emerge due to improper conditions of storage and transportation; a deficit of food could be caused by ineffective management of material flows. In the agrarian sphere, quality management forms cumulative effectiveness, which is manifested through control of parameters and consumer property of goods, search for the methods to reduce transaction costs, an increase in the level of adaptability to market conditions, and, as a result, strengthening of the general sustainability of the agrarian economy.

3.2 Tools of Quality Management in The Sphere of Agriculture and Food

The basis of the sustainable development of the agrarian economy and food security in the modern world is progressive tools of quality management in the sphere of agriculture and food. These technologies or best practices are complex, scientifically justified measures and systemic actions that ensure a high level of productivity,

resilience against risks, safety of food products, and traceability of food origin and minimization of its negative impact on the environment.

The intricacy of processes in agriculture and differences in access to innovative tools of management cause significant differences between practices of quality management in agriculture (Michelson et al., 2023). Depending on the direction and mechanism of influence, all these practices can be divided into the following groups:

- Regulatory and organizational tools of quality management.
- Technical & technological tools for ensuring high quality of food.
- Environmentally-oriented systems of quality management in agriculture.
- Socioeconomic tools.
- Institutional and infrastructural actions.

Each of these directions has a large potential in the sphere of product quality improvement and the resolution of food security problems. In aggregate, they form a coherent mechanism that contributes to solving complex multi-level tasks of the agrarian economy development and quality management of food products to raise the population's living standards and ensure the sustainability of the food system. The basis of the regulatory and organizational tools of quality management is formed by standards of quality management (ISO 22000, ISO 9001), systems of analysis of risks and critical control points (HACCP) (Lee et al., 2021) with prerequisite programs (GHP, GMP, GAP), industry standards (Global G.A.P., BRC, IFS) (Global G.A.P., 2020), and verification and audit mechanisms of compliance control, harmonized within international initiatives of the Global Food Safety Initiative (GFSI). Technological tools cover the methods of precise farming, automation of control of processes, digital monitoring of the parameters of quality, etc. These tools are based on the use of sensors, traceability systems, and IoT-connected systems, and involve the use of biotechnologies and agricultural innovations (Figure 1).

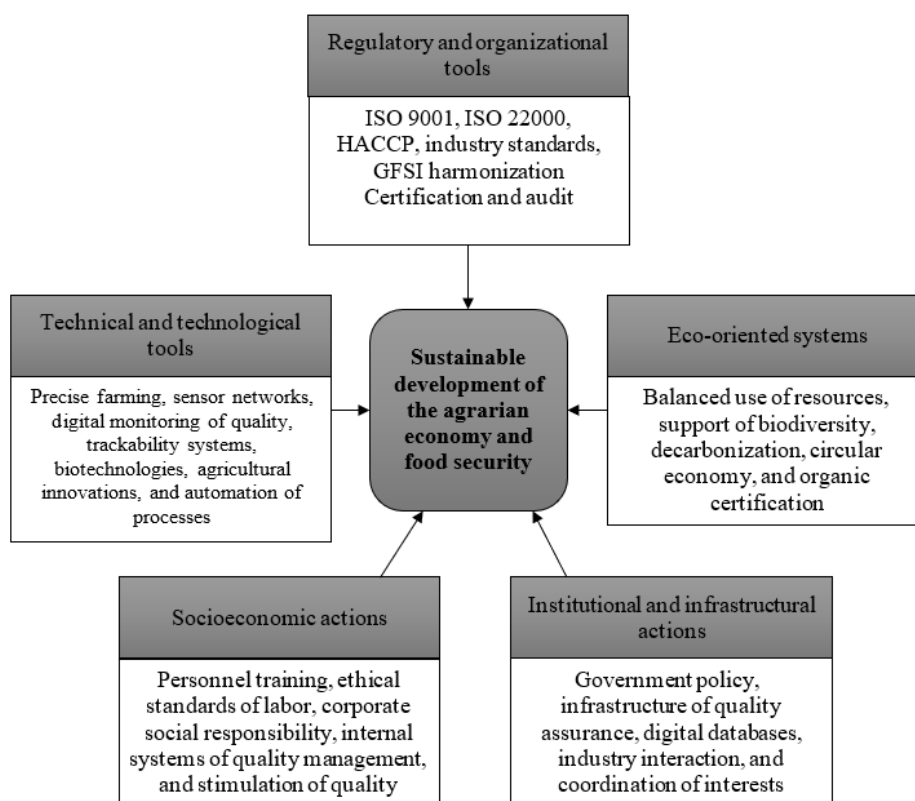


Figure 1. The integrated scheme of the best practices of quality management to support the sustainable development of the agrarian economy and food security

Source: Compiled by the authors based on (Bogoviz et al., 2018; De Baerdemaeker & Saeys, 2015; Lee et al., 2021; Osmonalieva et al., 2025; Peres et al., 2025; Sozinova et al., 2022)

The environmental direction contains a large list of initiatives concerning the balanced use of soils and water resources, support of biodiversity, decarbonization, implementation of the circular models of agricultural production, improvement of the effectiveness of resource use, application of environmental certification, etc.

(Alaoui et al., 2020; Al-Shammary et al., 2024). Together with the achievement of the environmental effect, these processes form the basis for long-term support of food security and improvement of product quality, based on the demands for sustainable development.

Socioeconomic directions of managerial practices in the sphere of agrarian economy development are realized through personnel training, implementation of ethical standards of labor, the use of the principles of corporate social responsibility, development of internal economic systems of quality management, and stimulation of activities aimed at compliance with high standards of food quality. At the institutional level, the main tools of quality management and food security are realized through the elements of the government policy, infrastructure of quality assurance, the use of logistical platforms and digital databases, and cross-sectoral interaction (Burgess et al., 2023). The focus is on the coordination of the interests of agricultural producers, intermediaries, processing companies, trade networks, and state regulation bodies.

The general scheme of the influence of the best practices of quality management on the sustainable development of the agrarian economy and food security is shown in Fig. 1. It contains blocks characterizing the real directions of formation of the best practices of quality management and support of the agricultural sector's sustainability. Within each block, the main tools, systems, and actions are given, which determine the type and character of the factors' influence on the studied processes.

On the whole, the concept of the best practices of quality management in agriculture can be viewed as a complex approach to systematization and standardization of production and management for quality and safety support, growth of the economic effectiveness, and reduction in the negative impact on ecology. The system of quality management within best practices combines process management, technical protocols, organizational structures, and transparency tools. The main criteria that allow distinguishing the best practices of quality management in the agrarian sphere are systemic character, scientific and technical confirmation, correspondence to international standards, traceability, availability of the proper system of metrics, and suitability for scaling.

The current systems of standardization of best practices are based on combining several institutional sources, each of which reflects different levels and conditions of standardization. The fundamental basis of quality management systems, and, accordingly, the formation of best practices, is the International Organization for Standardization (ISO). This organization determines the fundamental methodological basis for quality management, which uses the range of standards ISO 9000 and industry-specific standards for the food industry.

The main coordination role in the formation and development of best practices of quality management of food products is performed by the Food and Agriculture Organization of the UN (FAO). Among other tasks, this

organization develops and promotes proper Good Agricultural Practices (GAPs), whose aim is mainly to improve food production, support the quality of food products and safety, environmental justification of production, and quality management at all stages of value chain formation. Together with the World Health Organization (WHO), FAO develops valuable guidance for product quality, which is realized through Codex Alimentarius and determines key recommendations for food products hygiene (De Baerdemaeker & Saeys, 2015).

Through the direct connection with the primary link of production, the use of best practices with quality management in the agrarian economy is realized through the Global Good Agricultural Practice (GLOBAL G.A.P.). This standard regulates a wide range of operational and managerial activities, from water resources and soil management, livestock health, the use of chemical means of plant protection, to social standards of labor. In practice, GLOBAL G.A.P. is harmonized with standards of food product safety, which is especially relevant for the organization of audits within individual supply chains. In some cases, national management institutions in the sector of agriculture adapt this standard for national conditions, coordinating it with their regulatory standards (Crandall et al., 2017). The effective tools for quality assurance and food products safety also include the Global Food Safety Initiative (GFSI), which emerged in the early 21st century to develop a unified system of control and verification of food products safety, which allowed for coordination of the standards of food products safety and reduction in the cases of replication or lack of coordination of audits.

Transformation of abstract regulatory demands into concrete practical activities requires reconsideration of the corresponding mechanisms that influence the effectiveness of agricultural production. Three fundamental attributes of the applied dimension of the best practices of quality management are distinguished: contextual adaptability, measurability of results, and cumulative character of knowledge. These attributes explain the mechanism of transforming standards into practical results and determine the theoretical basis for new managerial innovations. Contextual adaptability characterizes production systems' ability to adapt quality management depending on size, available resources, conditions of functioning, etc. Measurability of results is formed around the use of practical tools for recording events and phenomena and their critical assessment. The cumulative character of knowledge points to production systems' ability to form, develop, and disseminate the best practices of quality management due to the accumulation of knowledge, practice, and experience.

Depending on the specifics of agriculture, the best practices of quality management could be realised through direct operational examples. Thus, GP standards can be implemented through the correct choice of land

plot (soil) for crop cultivation, planting the best seeds, the use of optimal means of chemical treatment, and compliance with technological conditions of production, harvesting, and post-harvest operations.

In the sphere of agricultural production of goods aimed at further processing, good manufacturing practices (GMP) and proper hygienic practices (GHP) are used. This contributes to the quality and safety of products at all stages, from receipt of raw materials to sales of final products. The main characteristics of these standards are detailed documentation and standardization of processes, which involve the development of standard operating procedures, determination of control parameters, and application of tools of control and verification of their observation.

Additional opportunities for implementing best practices in quality management in agriculture are realized through digital transformations. The basis of such actions is determined by the systems of sensors based on the Internet of Things, big data analytics, blockchain solutions, etc. Integration of smart sensors and the IoT into the systems of quality management of agricultural companies creates a possibility for a proactive approach to the management of production and distribution processes through industrial and manufacturing engineering.

Due to these technologies, there arises a possibility to trace the processes of production, ripening, harvesting, and product sales in real time. It is also possible to regulate the irrigation and temperature regimes, soil quality, etc. Access to these data allows for precise and quick correction of production processes and improvement of product quality. The integration of sensors and AI tools forms an effective tool that can

ensure uninterrupted monitoring of the growth of agricultural plants. It also allows for better planning of the workforce and equipment usage and distribution of assets according to the data collected in the process of ripening.

Thus, based on a review of advanced international experience drawing on SDG 2 implementation reports, FAOSTAT statistics, and empirical data from ISO, the WTO, and the Global Food Safety Initiative, as well as an analysis of the latest achievements in industrial and manufacturing engineering for agricultural product quality at smart vertical farms, a significant contribution of quality engineering to the sustainable development of the agricultural economy and food security has been established.

3.3 Systems Engineering Model of the Agricultural Quality Chain

From an engineering perspective, the agricultural economy is viewed as a sequence of technological stages analogous to an industrial production line: soil preparation, sowing, crop management, harvesting, primary processing, storage, transportation, and distribution. At each stage, input resources, control actions, output quality parameters, and acceptable ranges of deviation are specified.

Best quality management practices are described as a set of engineering solutions (ISO/HACCP/GLOBAL G.A.P., IoT monitoring, and precision agriculture) that make it possible to maintain these indicators within their target ranges. For this purpose, the “Integrated Agricultural Quality and Food Security Chain” framework should be used (Figure 2).

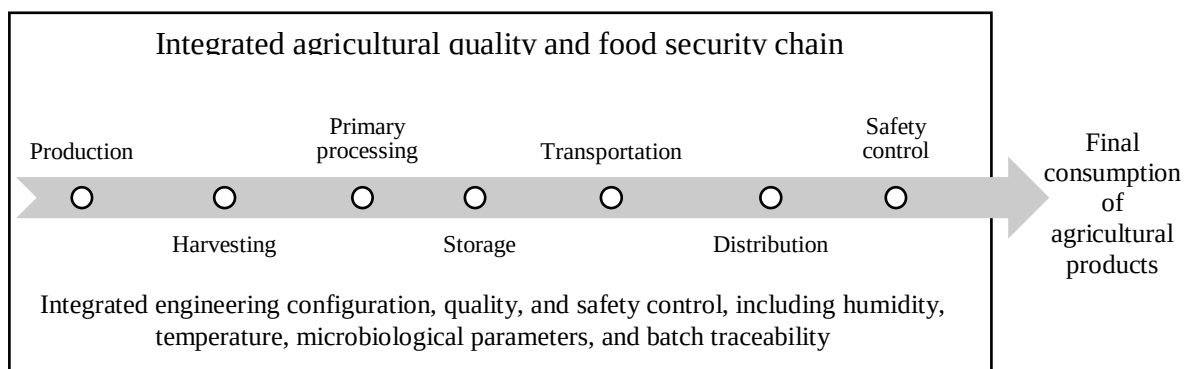


Figure 2. Integrated agricultural quality and food security chain
Source: Compiled by the authors

Figure 2 presents the following stages: production, harvesting, primary processing, storage, transportation, distribution, and safety control. For each stage, critical quality and safety control points are specified, including humidity, temperature, microbiological parameters, and batch traceability. The authors’ framework demonstrates that food security is the result of engineering configuration across the entire agricultural chain.

In EU countries, Canada, and Australia, HACCP systems and digital traceability are used to improve the quality and safety of food supply chains. Companies and agricultural clusters integrate data on product origin, storage conditions, and laboratory testing results into unified digital systems. This enables the rapid isolation of high-risk batches and reduces systemic food losses. From an engineering perspective, such practices

demonstrate that the sustainability of the agricultural economy is impossible without formalized quality and safety parameters at every stage of the chain.

4. DISCUSSION

The findings of this research contribute to the literature by Meng et al. (2026), Parihar et al. (2026), Silva et al. (2026), and Zhang (2026) and further develop the theoretical concept of industrial and manufacturing engineering for smart agricultural production by providing a more comprehensive understanding of the need for and advantages of applying industrial and manufacturing engineering to improve agricultural product quality, enhance the sustainability of climate-smart agriculture, and strengthen food security.

In contrast to Filintas A. (2025), Mehmood et al. (2026), Purohit and Yogi (2025), and Xu et al. (2026), it has been substantiated that optimizing the organizational processes of climate-resilient farms, including standardization, certification, quality control, sorting and rejection of agricultural products, as well as their labeling and packaging, is insufficient to fully realize the potential for improving agricultural product quality at climate-smart farms. Achieving this goal also requires the optimization of technical processes through industrial and manufacturing engineering for agricultural product quality. Accordingly, the existing approach to quality management in smart agriculture requires adjustment.

The issues of sustainable development of the agrarian economy and support of food security, which are based on the use of the best practices of quality management in agriculture, are very relevant and cause active discussion in scientific and expert circles. The main issues that need to be discussed include those characterized by a higher level of priority. An important problem in the sphere of implementing and using the best practices of quality management in agriculture is the unequal access of agricultural companies to the leading technologies. Despite the large potential offered by innovative capabilities, a serious variation in the level of access to technologies among small, medium, and large companies restricts the possibilities for its development. Accordingly, the introduction of the mechanisms of overcoming the technological gap forms an important topic for further research.

Another aspect requiring in-depth research is the fragmentation of standardization and harmonization. The existence of many standards requires their coordination. In this context, the development of the models of integrated standardization, which would combine the tools of quality, safety, traceability, and correspondence to environmental and social criteria, would allow for a significant increase in the level of the agrarian economy's sustainability in the conditions of modern challenges. Theoretical justification of the connection between the quality of products and food security is another direction

for discussion, which is concerned with the need for empirical and more thorough scientific elaboration on the character and strength of this connection. Special attention in this direction should be paid to the development of a clear methodology of quantitative assessment of the influence of best practices of quality management in agriculture, the formation of the models of such influence, and their testing in practice. Resolution of this problem will allow selecting tools that conform the most to the local and sectoral context and have the largest potential from the position of the balance of economic, environmental, and social interests to ensure the sustainability of the agrarian economy's functioning. Thus, consistent with Juraev et al. (2024), Senthilkumaran et al. (2025), Song et al. (2024), and Wang et al. (2024), the initial hypothesis has been confirmed, and it has been scientifically substantiated that substantial and clearly observable improvements in agricultural product quality in smart agricultural production can indeed be achieved through the direct application of industrial and manufacturing engineering to quality management.

4. CONCLUSION

The novelty of the technical approach to quality management in climate-smart agriculture developed in this article lies in the systematic application of advanced agricultural quality management methods (intelligent sensors, blockchain, Big Data analytics, and the IoT) in combination with industrial and manufacturing engineering, which enables more sustainable development of the agricultural economy and strengthens food security.

The agrarian economy has a leading role in the global food system. At the same time, the sector faces an increase in risks caused by climate change, economic volatility, technological disproportions, and environmental restrictions, which negatively influence the resilience of production and producers' revenues. The modern agrarian sector is characterized by certain structural dysfunctions, which lead to a reduction in production quality and restrict the potential for development. The issue of quality acquires a strategic meaning in the agrarian economy, for it covers not only characteristics of products but the system of the management of processes, which ensures economic, environmental, and social efficiency. Quality management is a universal tool for raising effectiveness with the use of resources, minimizing risks, and strengthening trust in agricultural production. Institutionalization of management based on international standards, in particular, ISO 9001, HACCP, Codex Alimentarius, ISO 14001, and EMAS, contributes to the formation of effective production systems oriented towards constant improvement, traceability, and compliance with global demands for safety. This ensures integration of the agricultural sector into world markets,

raises its competitiveness, and creates conditions for the rational use of natural resources.

Best practices of quality management form the foundation for the sustainable development of the agrarian economy and food security, combining technological, organizational, environmental, social, and institutional approaches. They are aimed at raising productivity, reducing risks, ensuring the safety and traceability of food, and minimizing environmental impact. Regulatory and organizational mechanisms, based on ISO, HACCP, and Global G.A.P. standards and GFSI initiatives, ensure coordination of processes and control of compliance. Technological tools, in particular, precise farming, digital monitoring, and the Internet of Things, raise the level of automation and analytical precision. Eco-oriented systems contribute to the rational use of resources and preservation of biodiversity, integrating the principles of the circular economy. Socioeconomic aspects are based on an increase in the competence of employees, observation of ethical norms,

and development of corporate responsibility, while the institutional and infrastructural level ensures state regulation, cross-sectoral coordination, and development of quality assurance systems. The totality of these elements creates a coherent mechanism of quality management, which ensures effectiveness, transparency, and sustainability of the agricultural sectors, as well as their ability for integration in the global food chains.

The practical value of the newly developed approach lies in establishing independent engineering and technical support for improving agricultural product quality, separate from productivity engineering in agriculture, and enabling advanced digitalization capabilities to be used for the targeted and maximum enhancement of product quality. This will make it possible to move from mere compliance with existing quality standards toward achieving quality levels that exceed current standards, followed by the revision of those standards toward higher agricultural product quality through enhanced industrial and manufacturing engineering.

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